USGS
science for a changing world

Earthquakes in the Cascadia Region: Where, when, and how?

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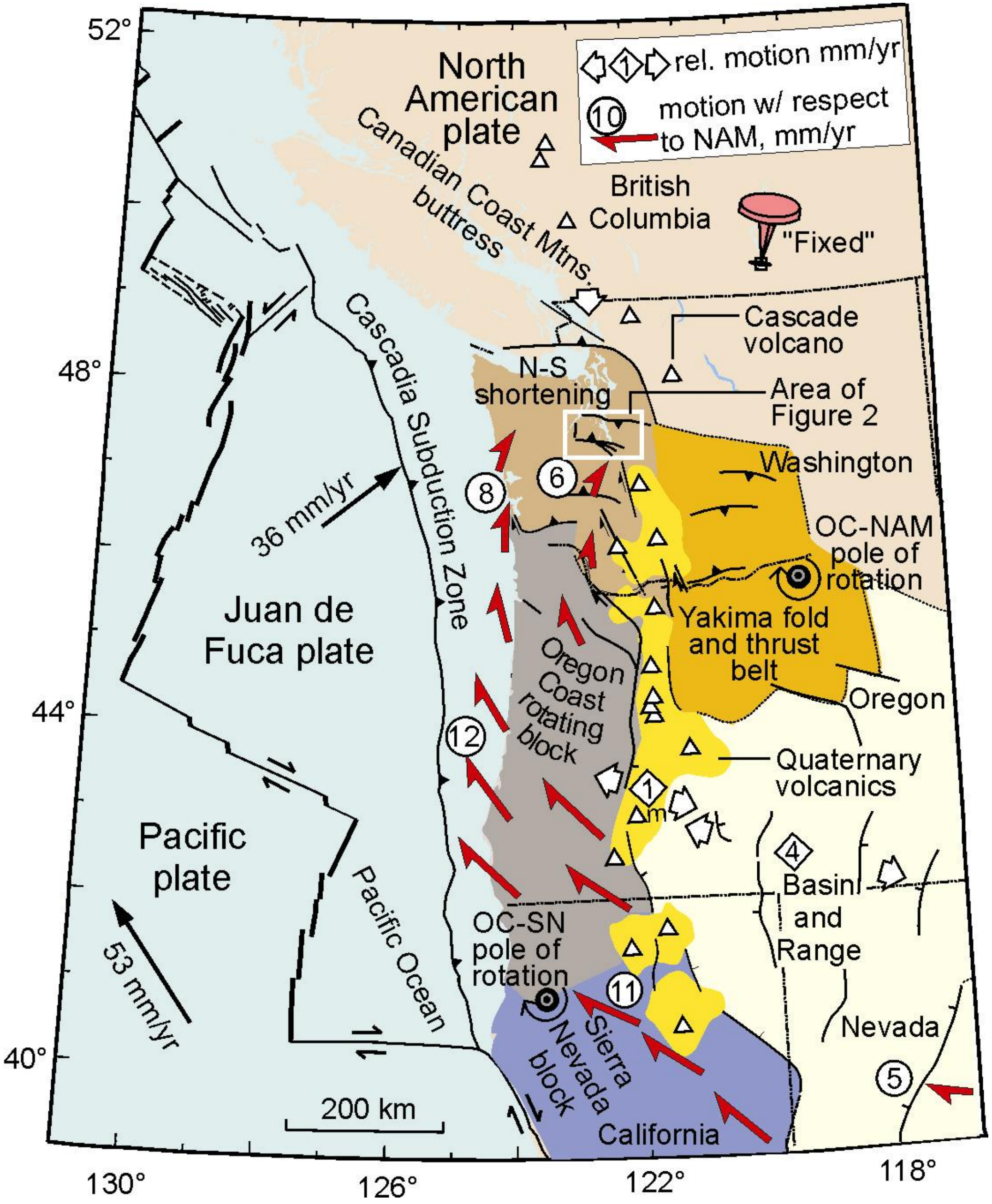
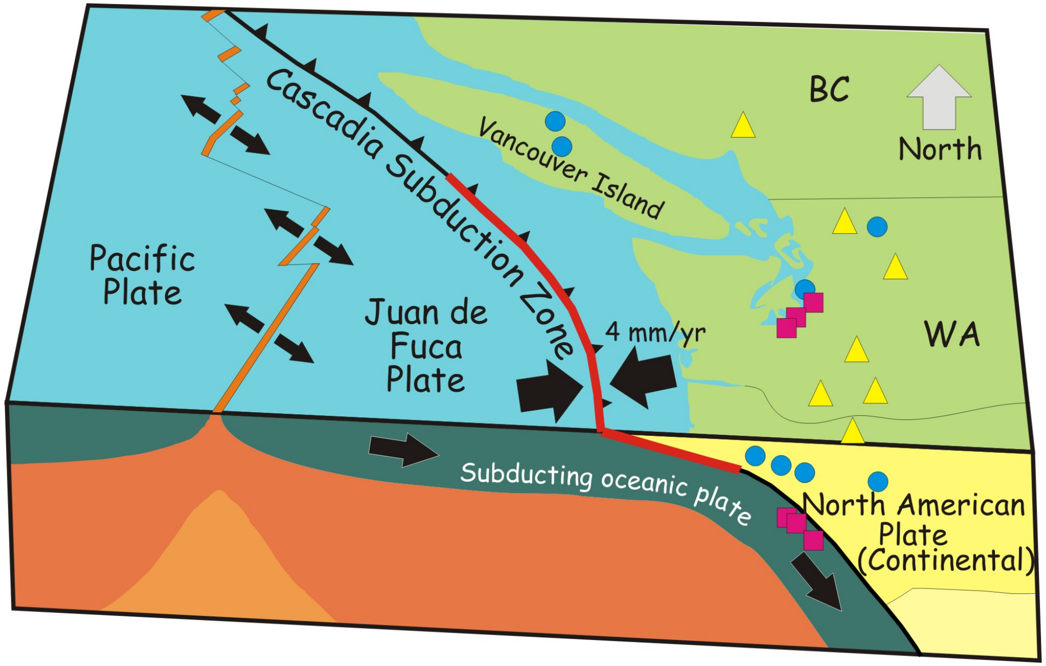
U.S. Department of the Interior
U.S. Geological Survey

N-S contraction inferred after removing effects of oblique E-W contraction from the subduction zone

D-DMFZ is the inferred edge of “backstop”.

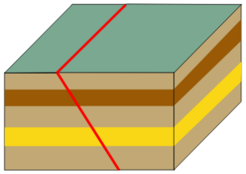


Three Fault Types

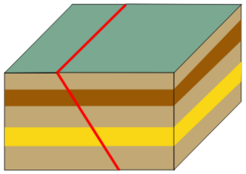


Earthquake Sources

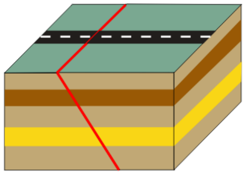
- ■ Deep earthquakes (Intraslab)
- ● Shallow earthquakes (in Nam)
- ╲ Subduction zone earthquakes
- ▲ Cascade volcano



1. Normal fault

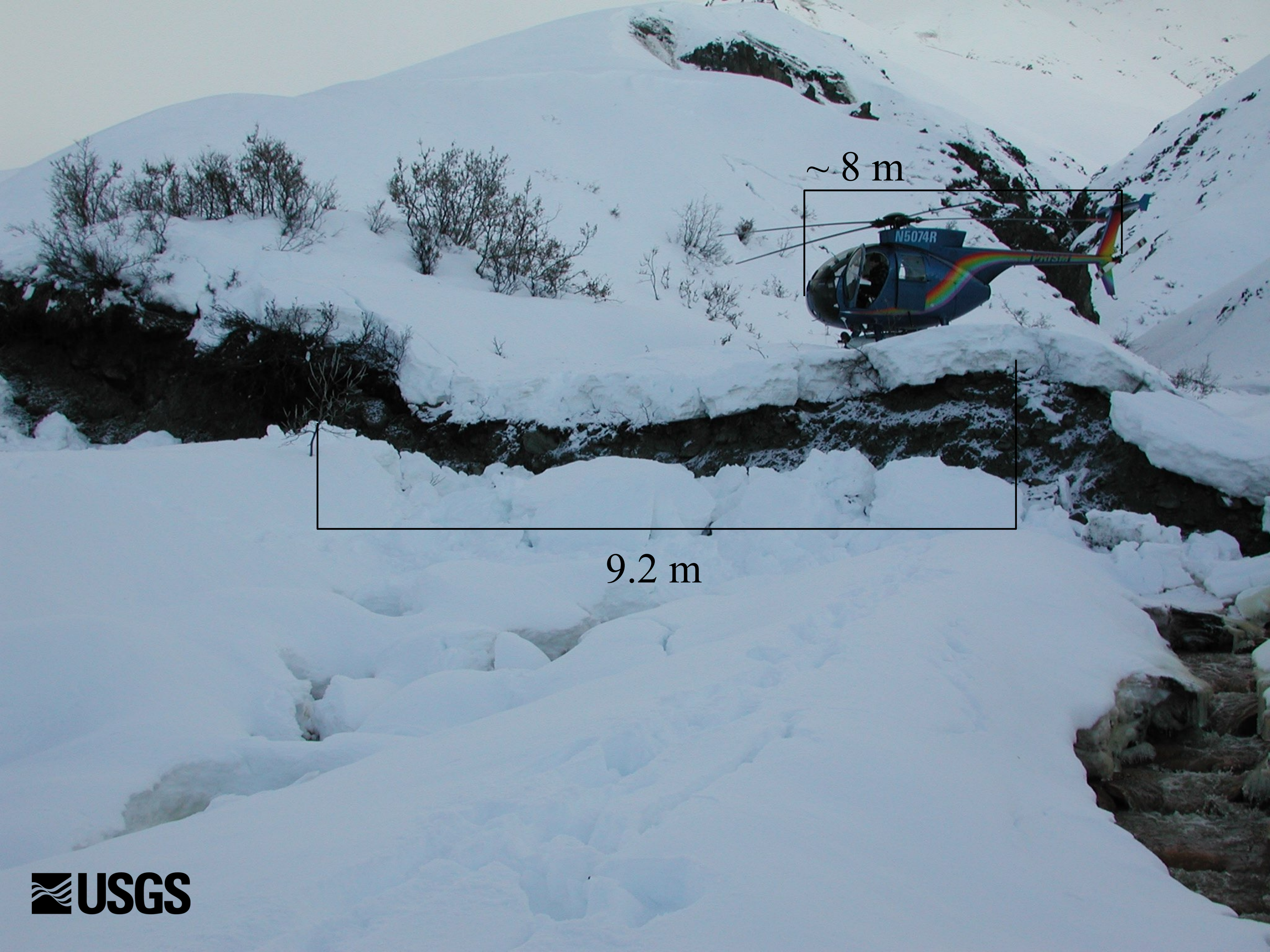


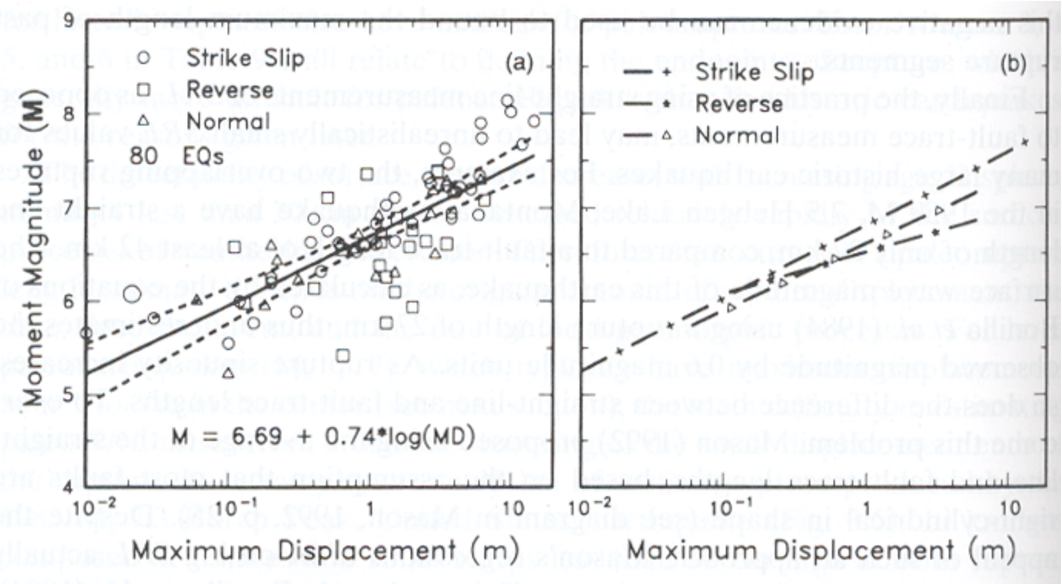
2. Reverse fault (or thrust fault)

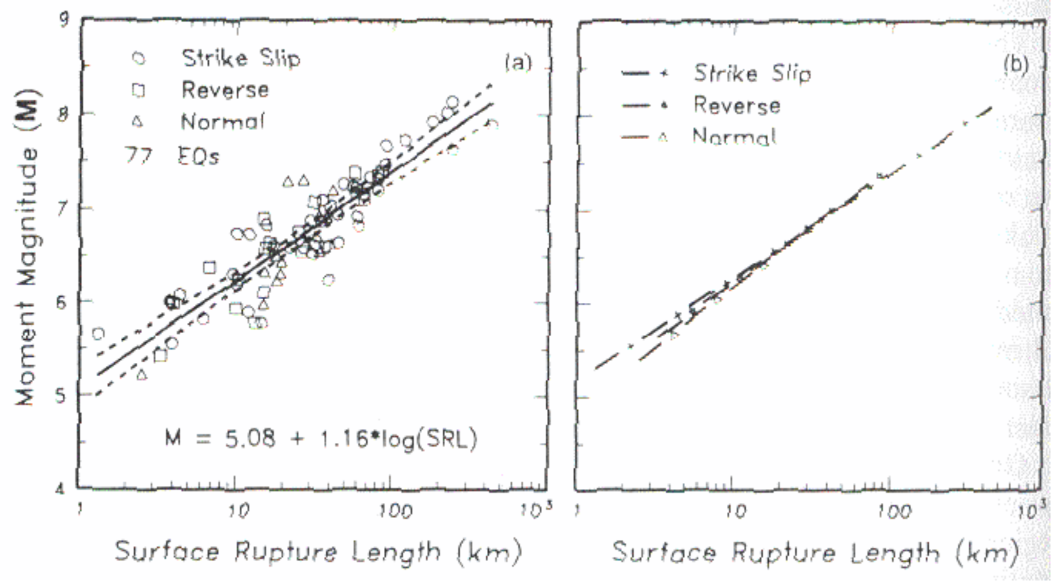


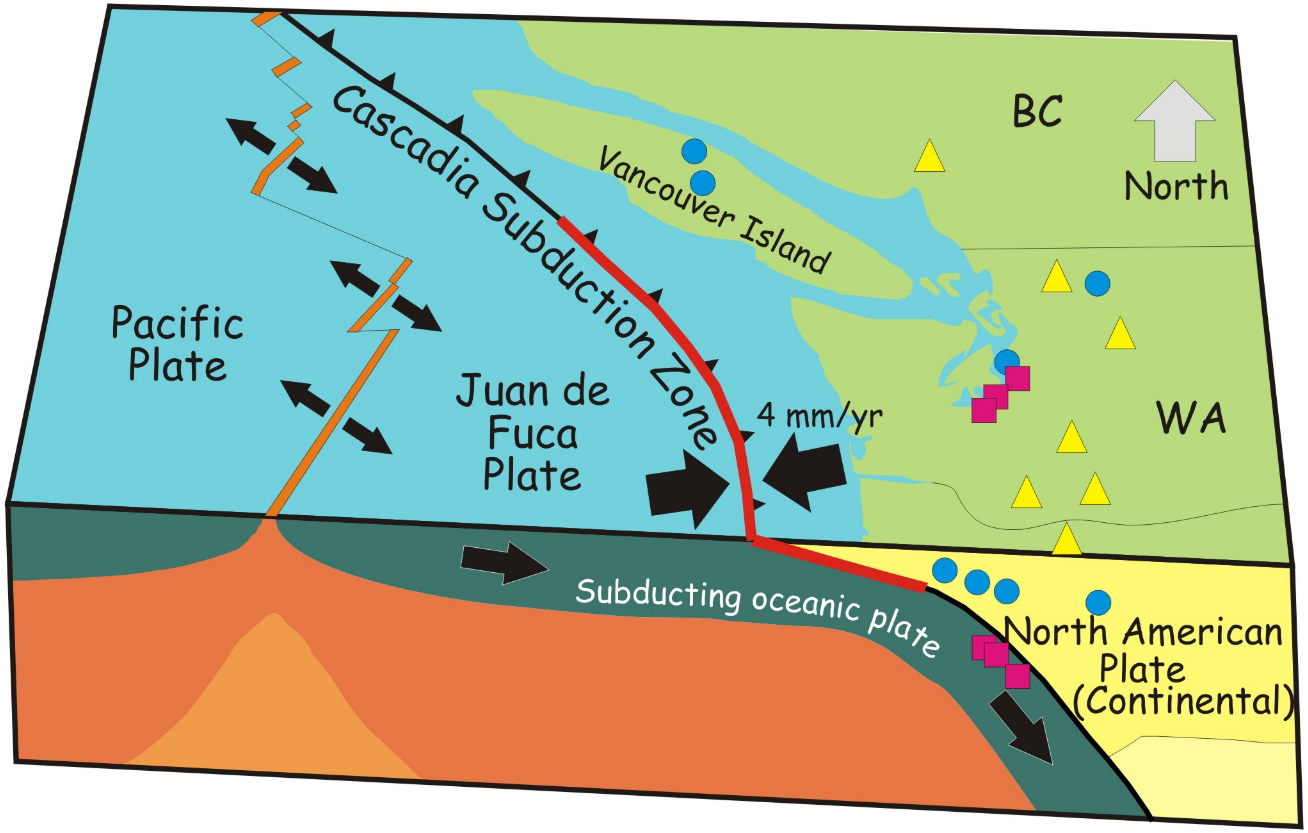
3. Transform fault

Fault scarp: a steep slope or cliff formed directly by movement along a fault and representing the exposed surface of the fault


~ 8 m
9.2 m
N5074R
PRISM


9
8
7
6
5
4
Moment Magnitude (M)
Strike Slip
Reverse
Normal
80 EQs
(a)
M = 6.69 + 0.74*log(MD)
10^{-2}
10^{-1}
1
10
Maximum Displacement (m)
Strike Slip
Reverse
Normal
(b)
10^{-2}
10^{-1}
1
10
Maximum Displacement (m)


9
8
7
6
5
4
Moment Magnitude (M)
Strike Slip
Reverse
Normal
77 EQs
(a)
M = 5.08 + 1.16*log(SRL)
1
10
100
10^3
Surface Rupture Length (km)
Strike Slip
Reverse
Normal
(b)
1
10
100
10^3
Surface Rupture Length (km)



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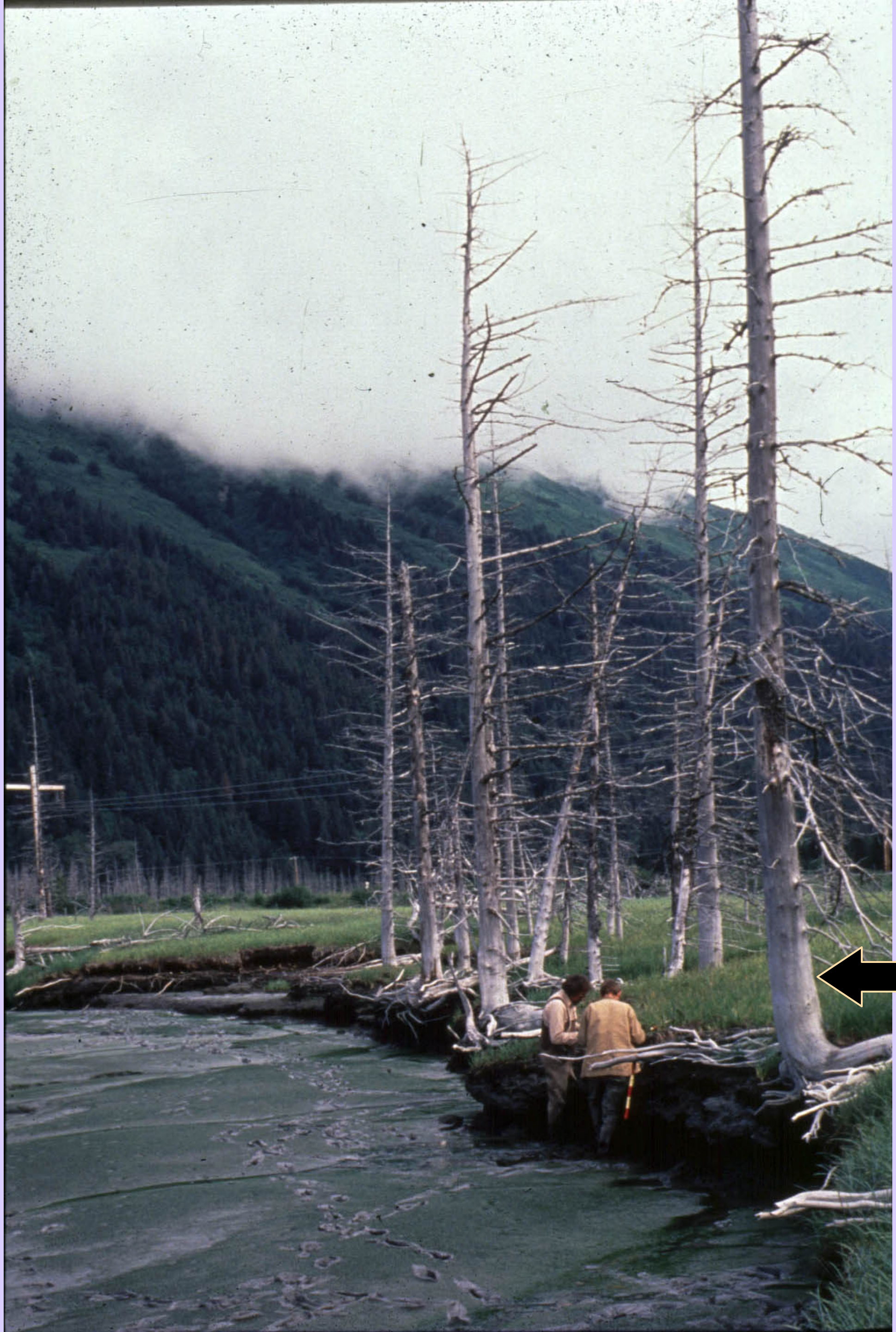


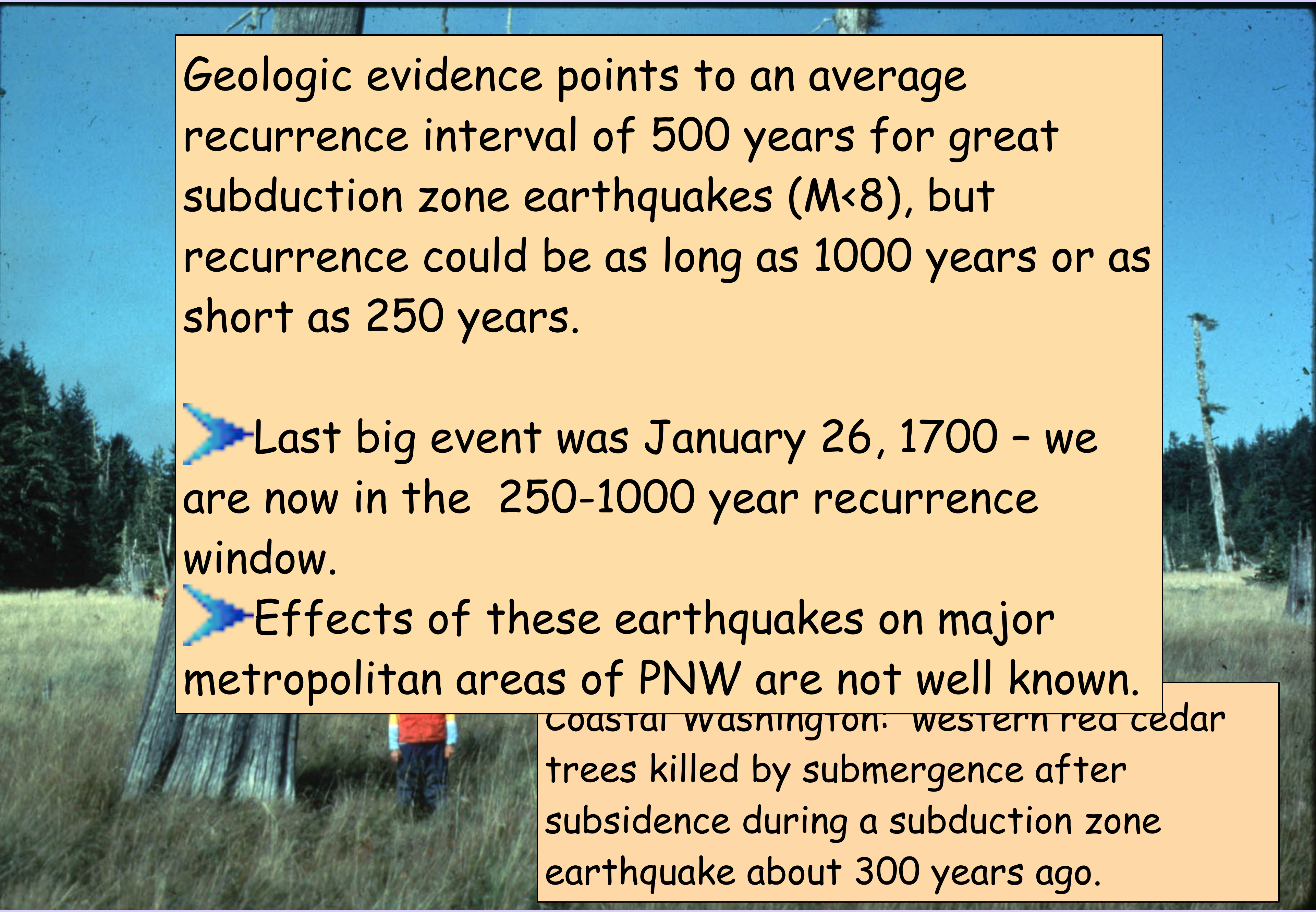
Lesson from 1964 Alaska Earthquake:

Areas of the coastline subside during great subduction zone earthquakes ($M_w > 8.0$).

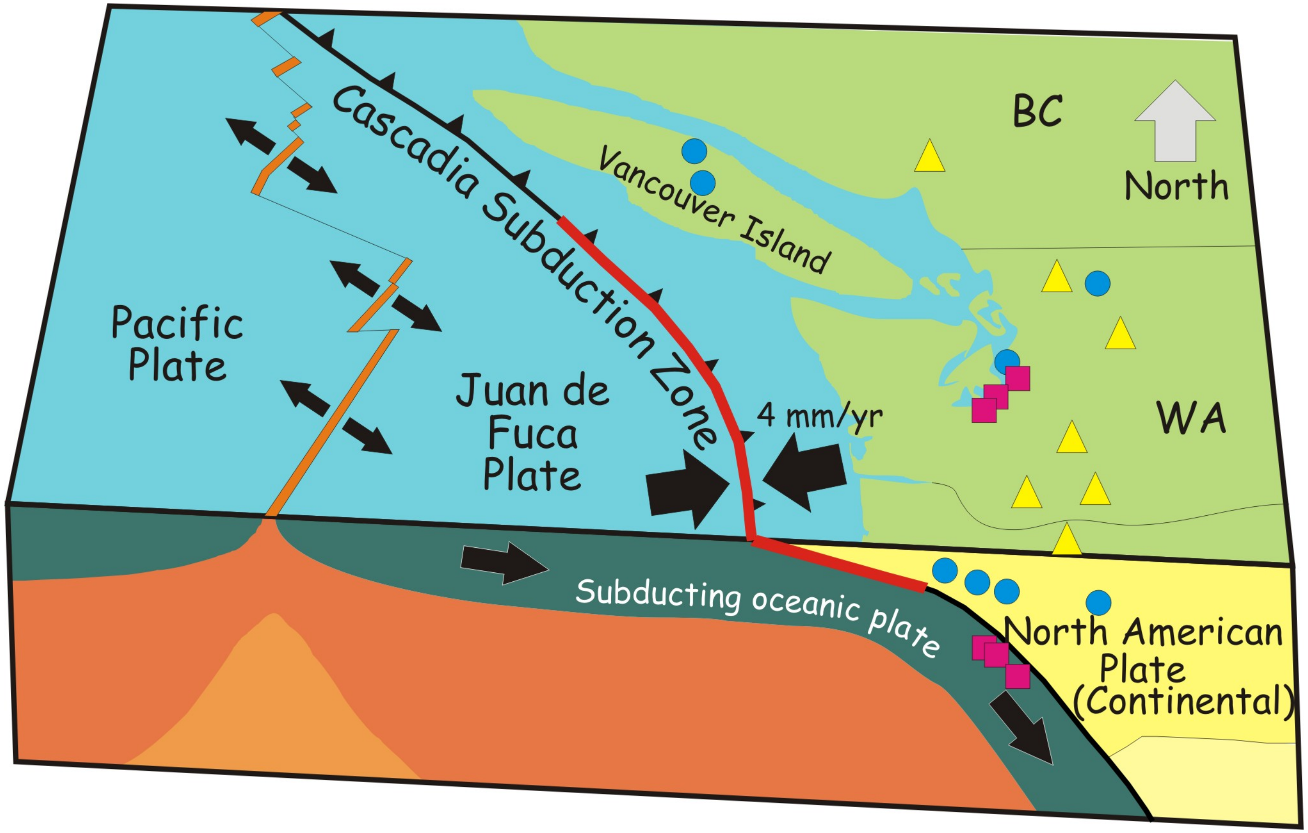
Spruce trees killed when saltwater flooded forest after subsidence lowered them into the intertidal zone

Geologic evidence points to an average recurrence interval of 500 years for great subduction zone earthquakes (M<8), but recurrence could be as long as 1000 years or as short as 250 years.

- Last big event was January 26, 1700 – we are now in the 250-1000 year recurrence window.
- Effects of these earthquakes on major metropolitan areas of PNW are not well known.



Coastal Washington: western red cedar trees killed by submergence after subsidence during a subduction zone earthquake about 300 years ago.



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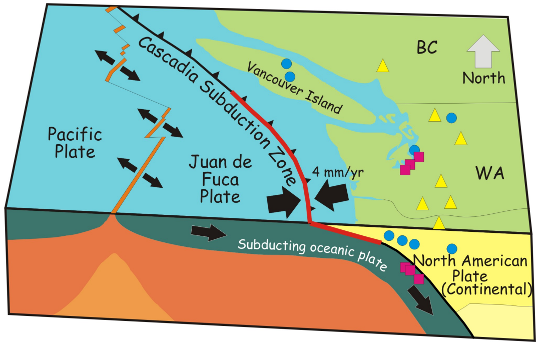
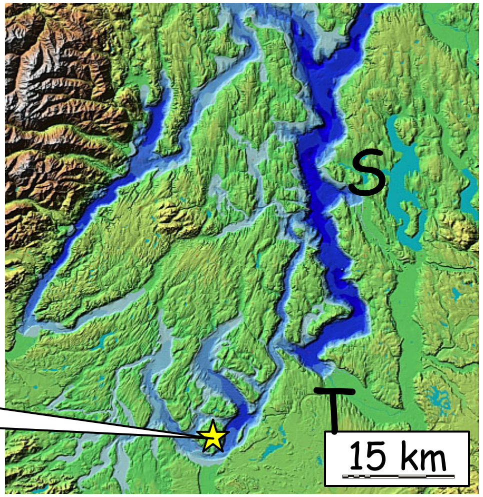
Nisqually Earthquake

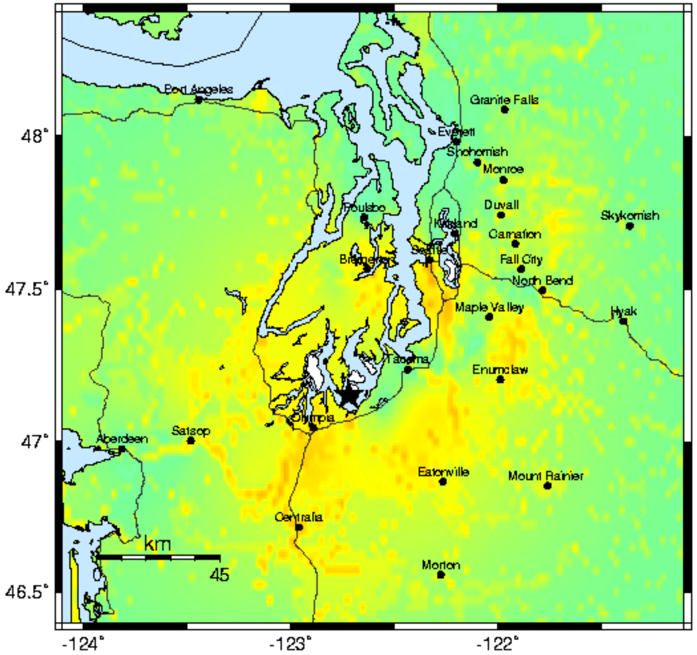
- Mw = 6.8
- Depth = 52.4 km (32.5 miles)
- Intraslab normal fault event





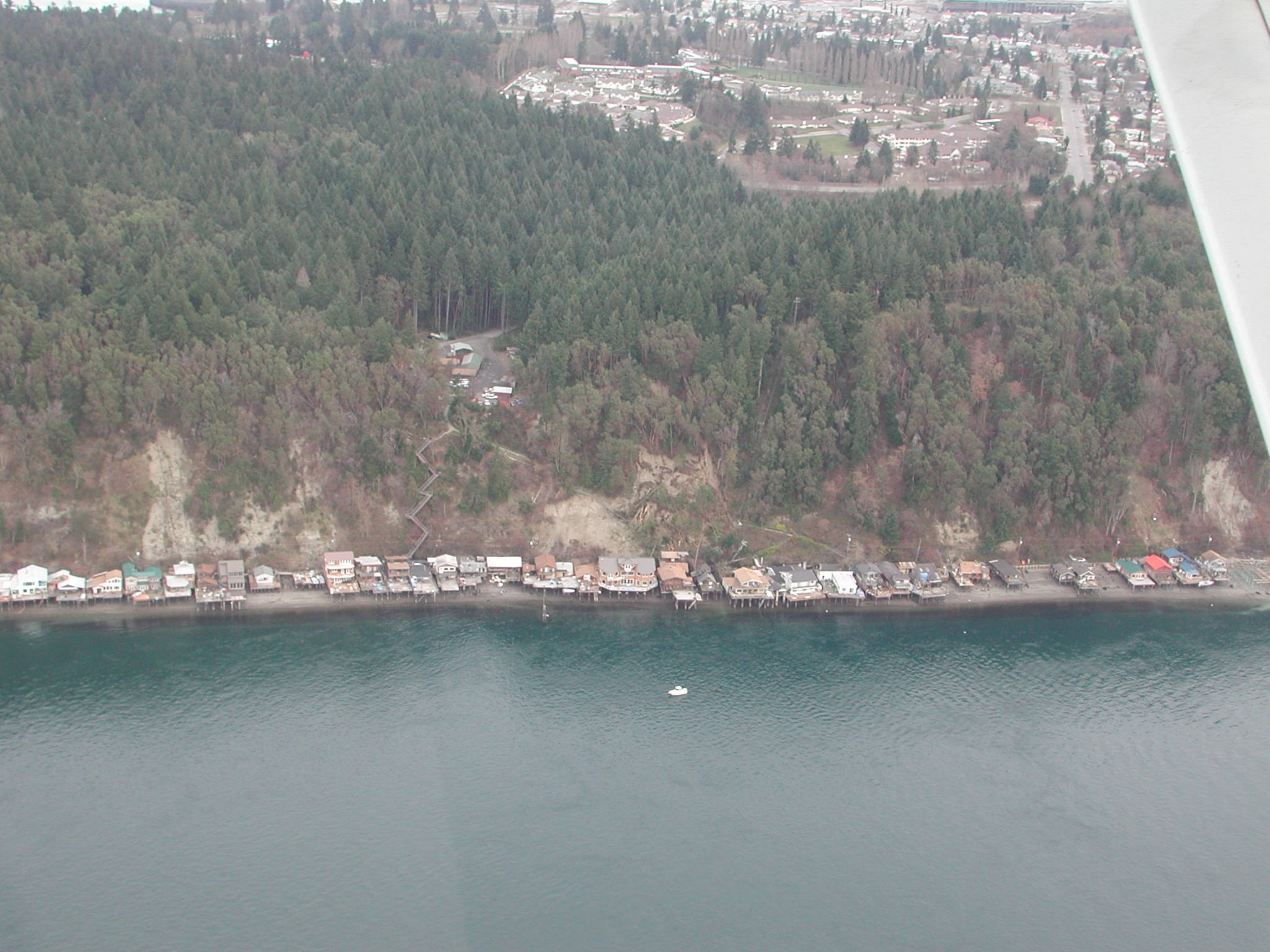
2/28/01
Mw = 6.8

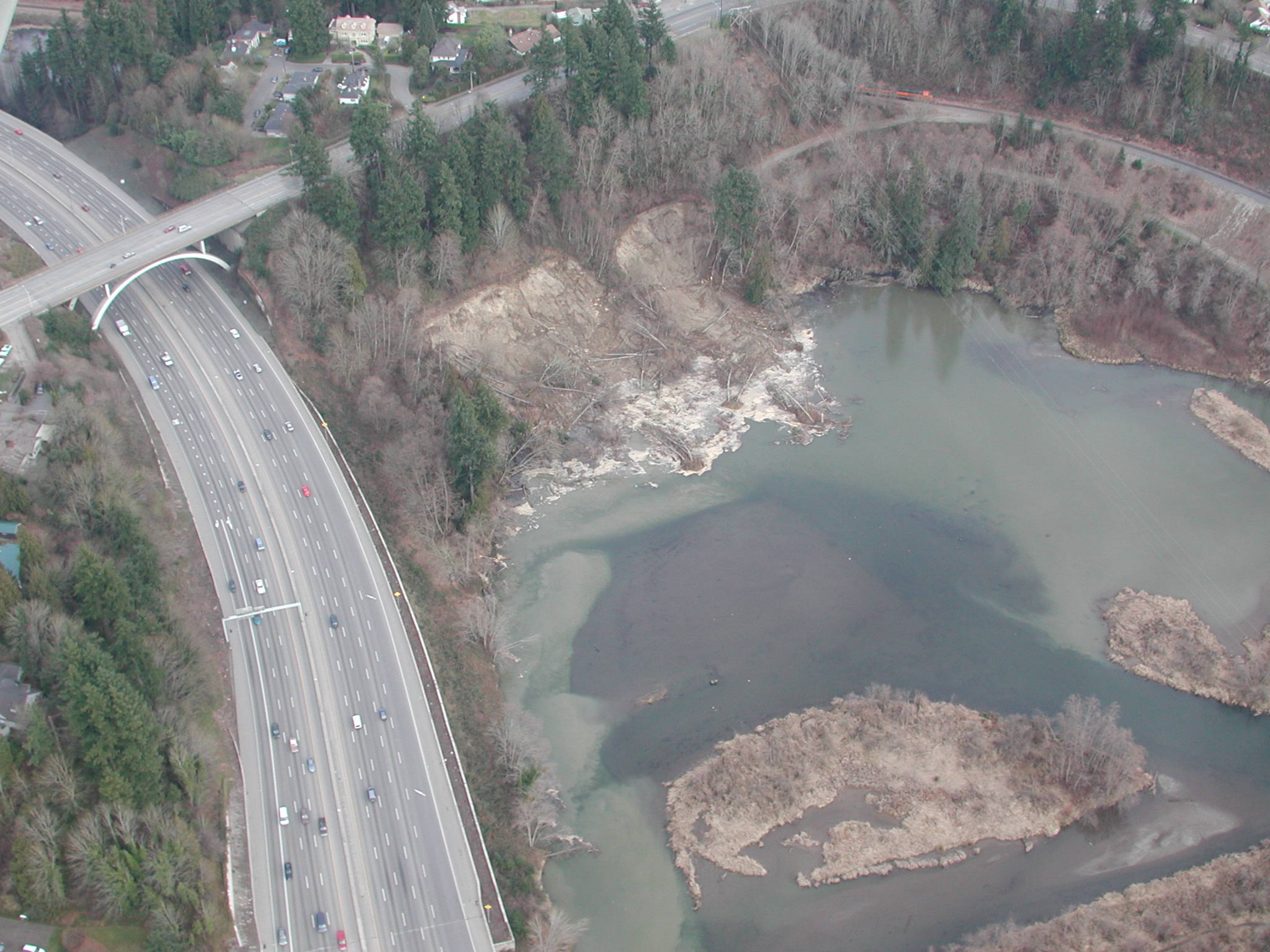
PNSN Rapid Instrumental Intensity Map Epicenter: 17.6 km NE of Olympia, WA
Wed Feb 28, 2001 10:54:00 AM PST M 6.8 N47.15 W122.72 ID:0102281654

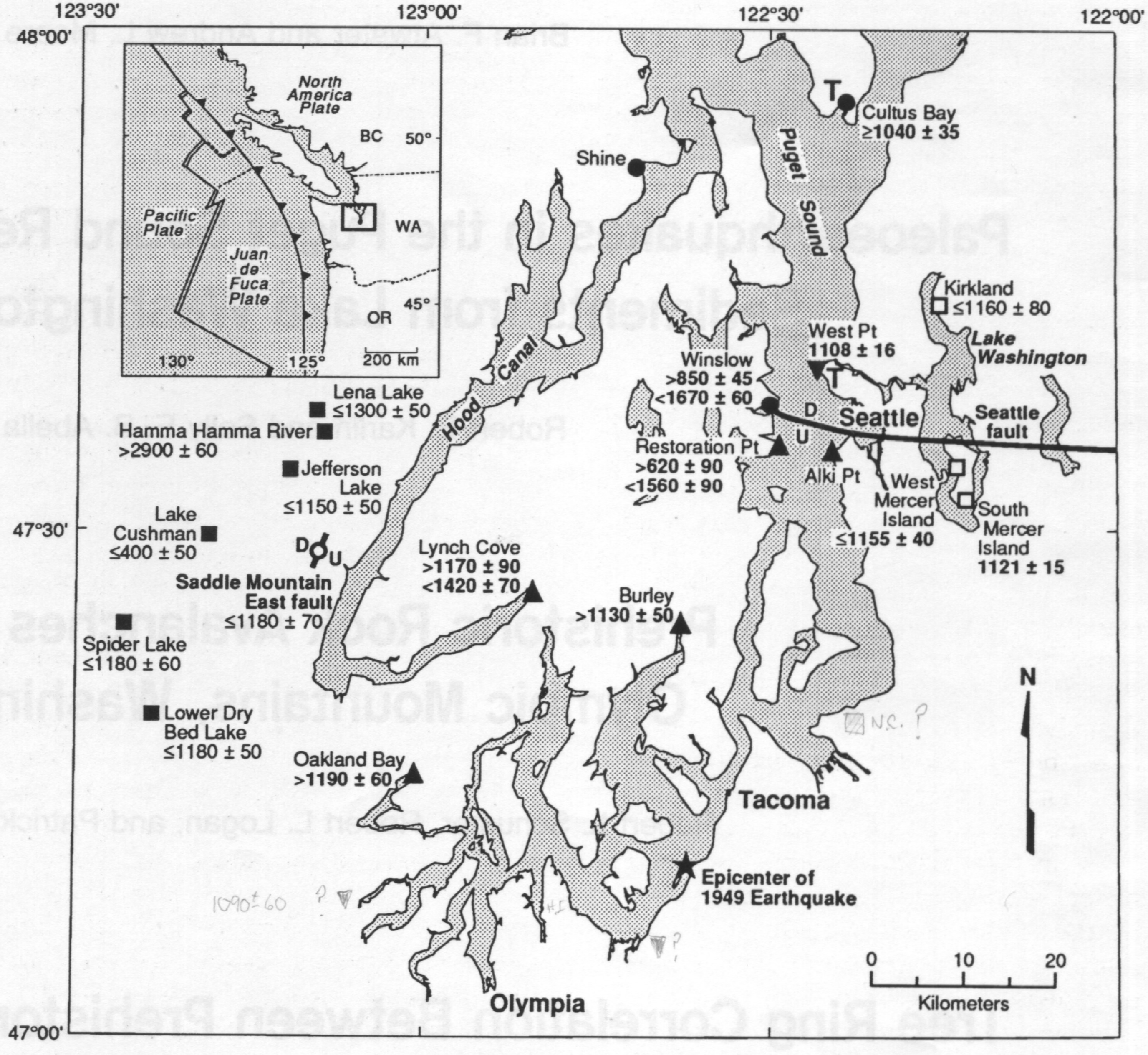


PROCESSED: Thu Apr 19, 2001 03:39:38 AM PDT.

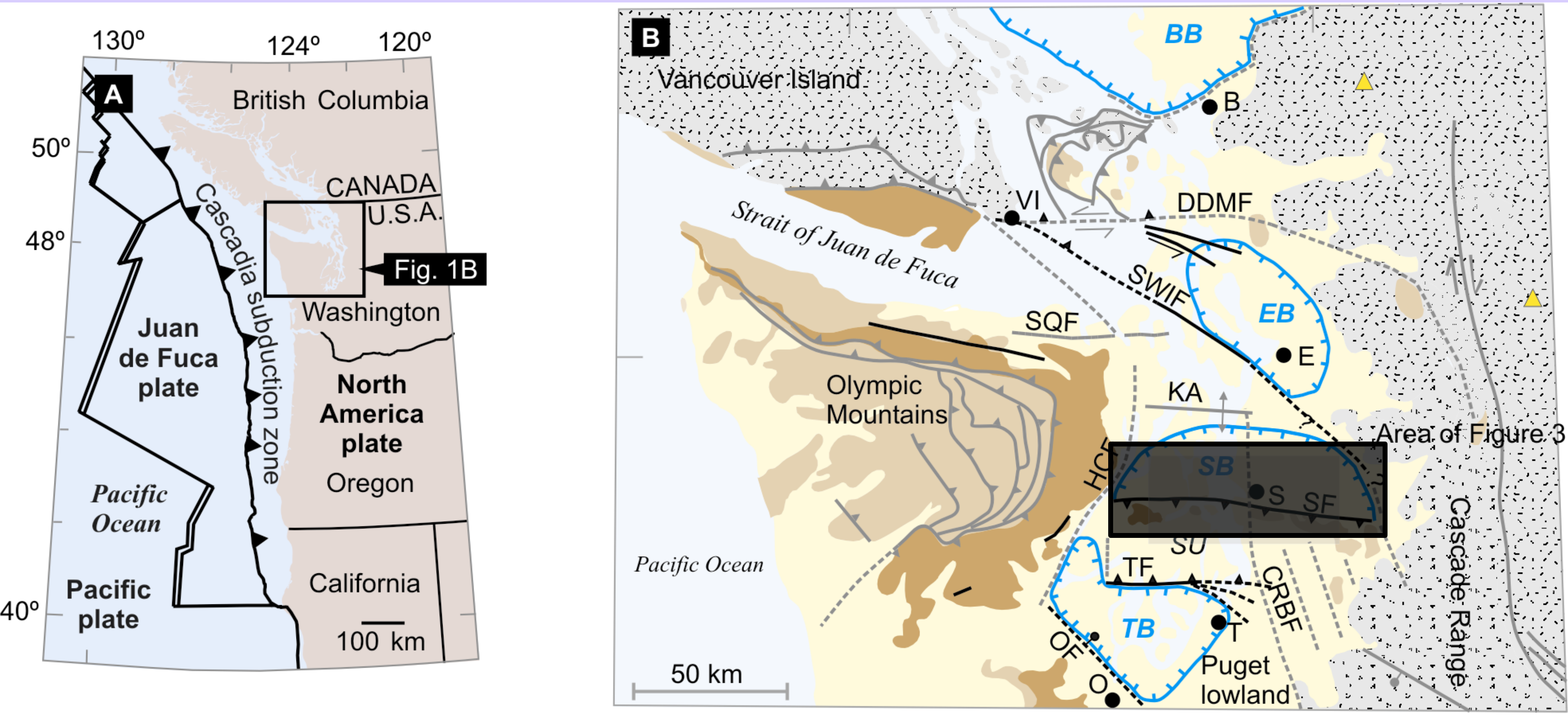
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+







(from Bucknam et al., Science, vol. 258, 1992)



Structural basin

Thrust fault (teeth on upthrown block), black where Holocene movement is known or suspected

Fault, black where Holocene movement is known or suspected

Fault (bar and ball on downthrown side), black where Holocene movement is known or suspected

Concealed fault, black where Holocene movement is known or suspected

Quaternary deposits

Sedimentary rocks (Paleogene to Neogene)

Cascade igneous rocks (Oligocene and younger)

Crescent Formation and other Eocene volcanic rocks

Basement rocks (pre-Tertiary)

▲ Quaternary volcano

Seattle Uplift

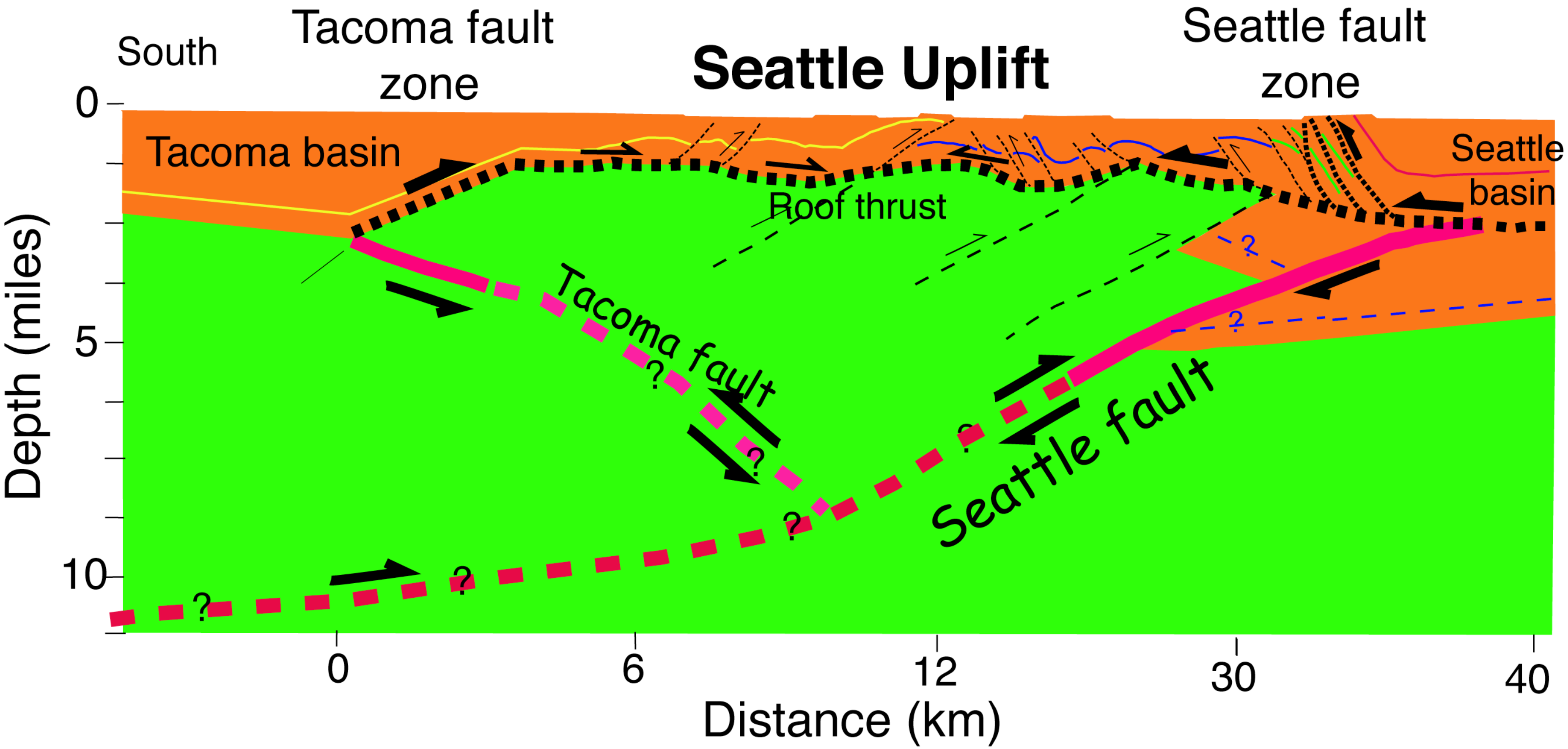
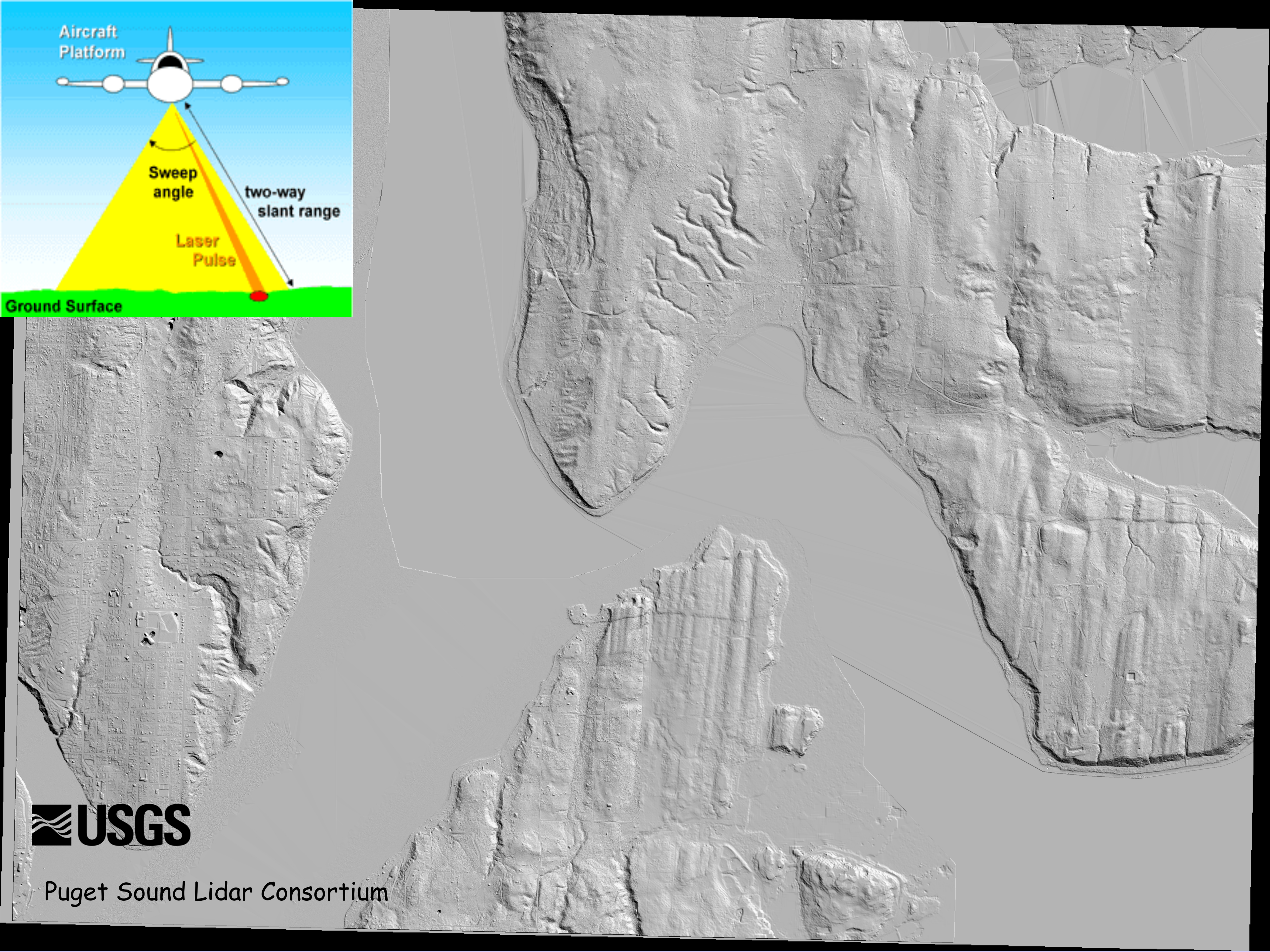


Diagram courtesy of Tom Brocher, U.S.G.S.



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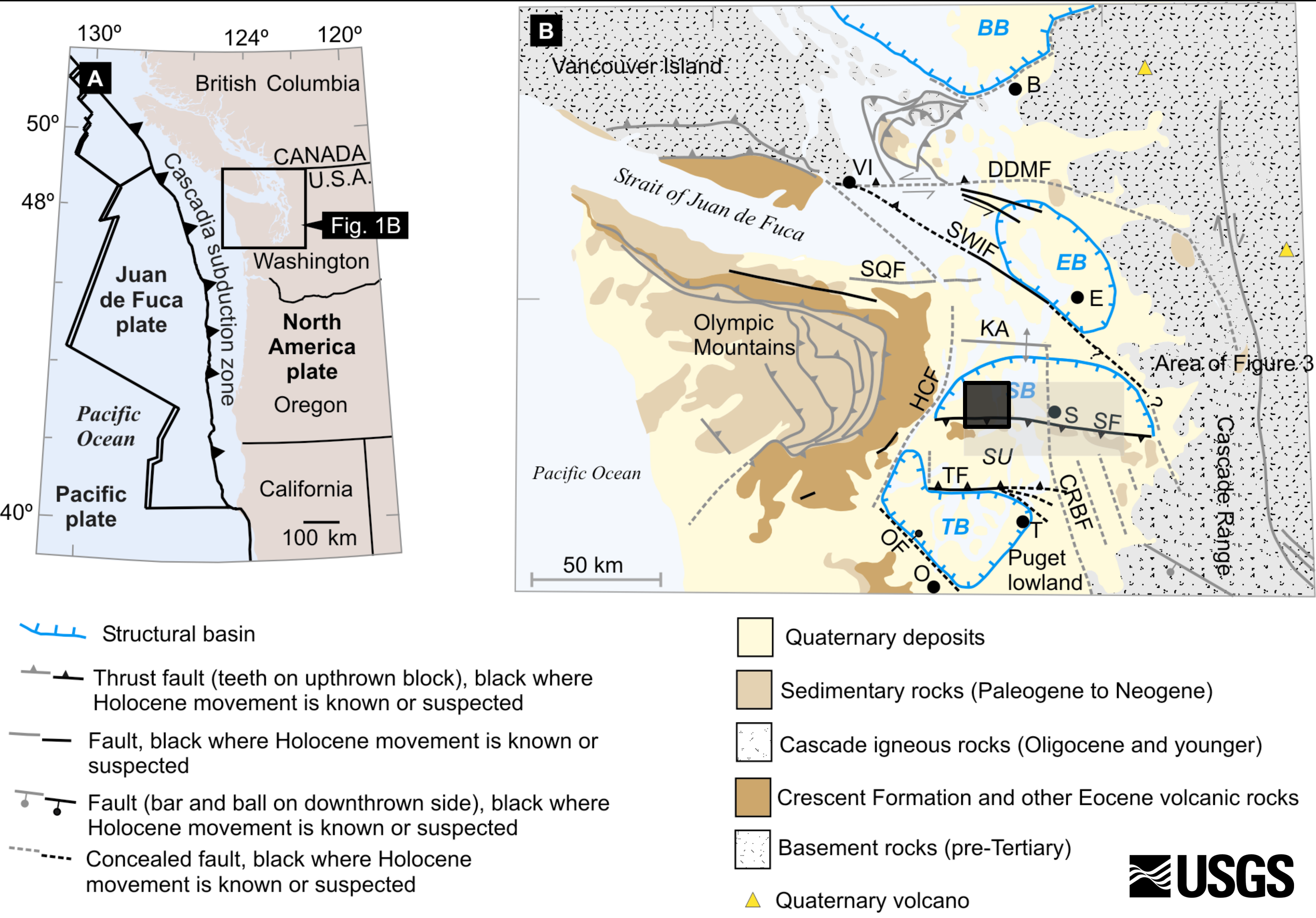
Puget Sound Lidar Consortium


A
130°
124°
120°
50°
48°
40°
British Columbia
CANADA
U.S.A.
Fig. 1B
Cascadia subduction zone
Juan de Fuca plate
Washington
North America plate
Oregon
Pacific Ocean
Pacific plate
California
100 km
B
Vancouver Island
BB
B
VI
DDMF
Strait of Juan de Fuca
SWIF
EB
E
SQF
KA
Olympic Mountains
HCF
SB
S
SF
Area of Figure 3
SU
TF
CRBF
TB
T
OF
O
Puget lowland
Cascade Range
Pacific Ocean
50 km
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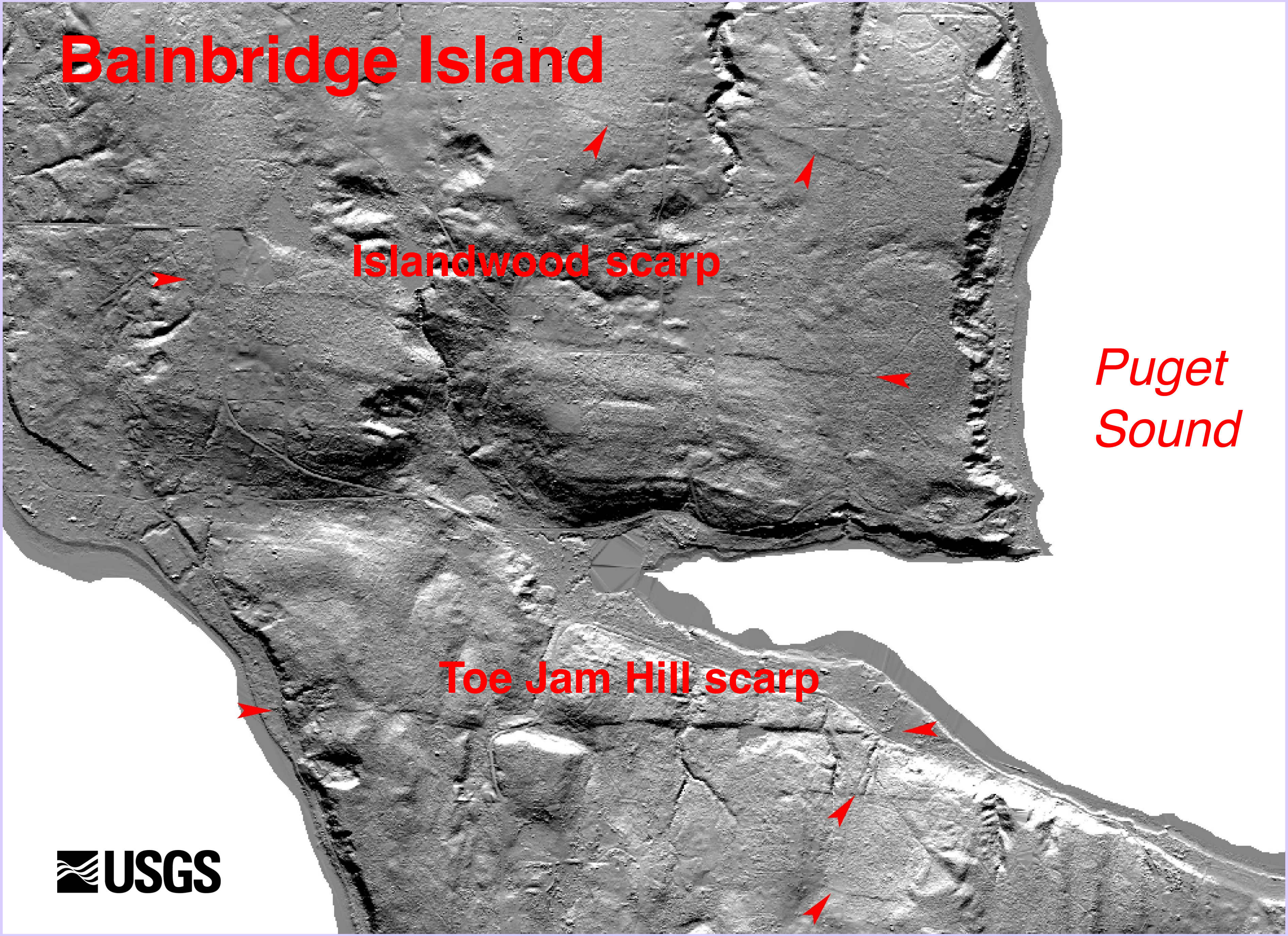
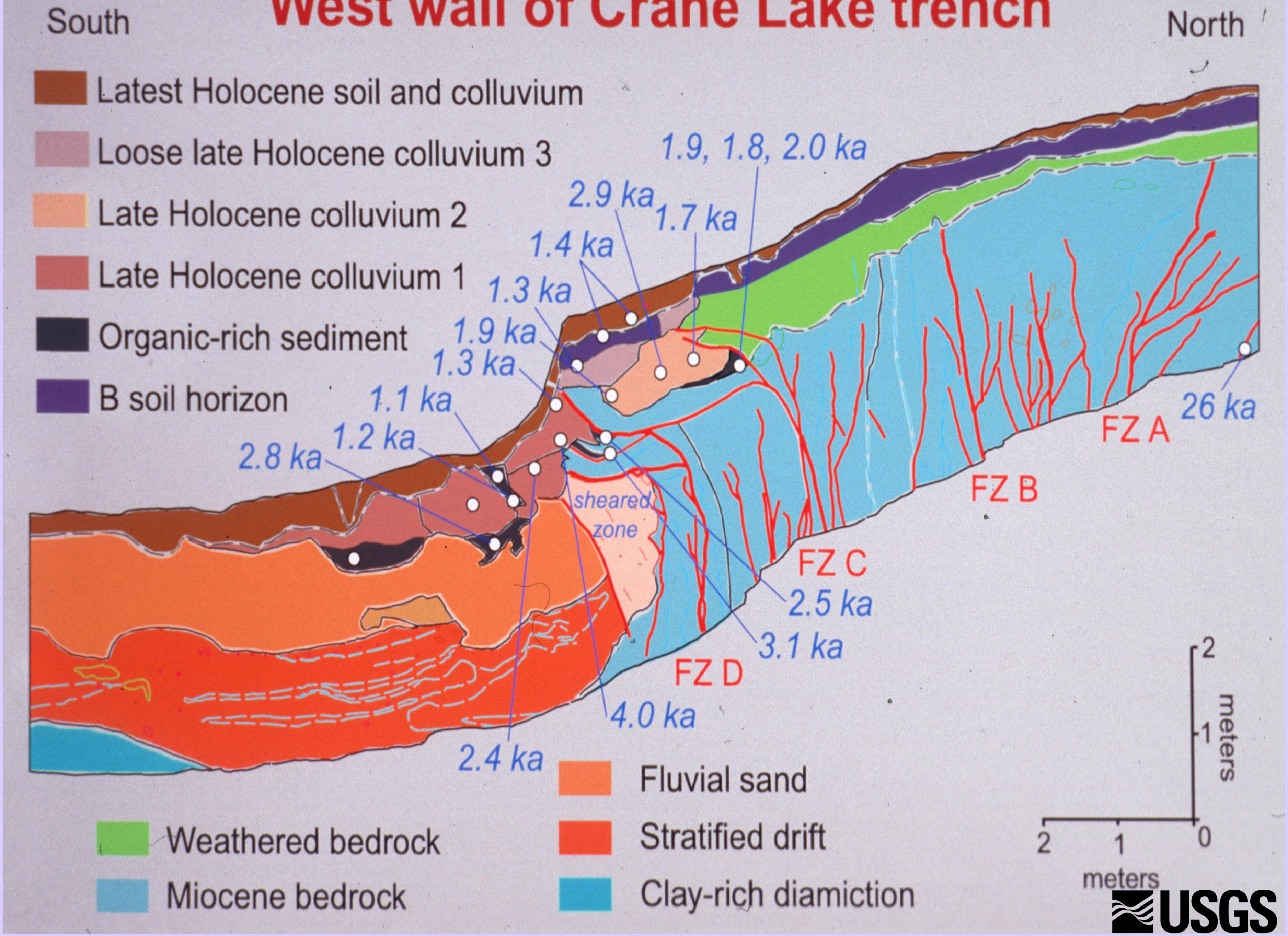
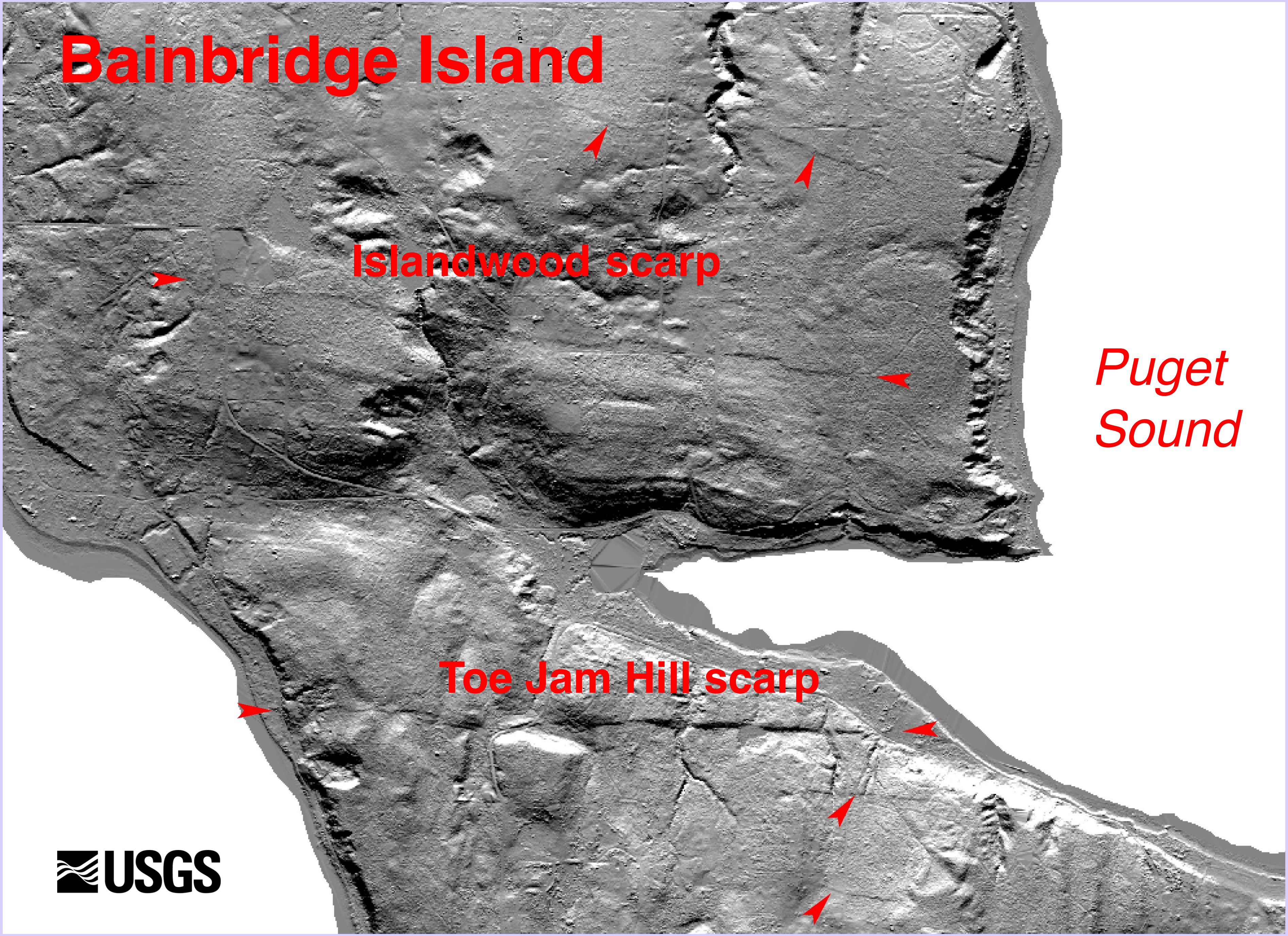
Basement rocks (pre-Tertiary)
Quaternary volcano


Bainbridge Island
Islandwood scarp
Puget Sound
Toe Jam Hill scarp

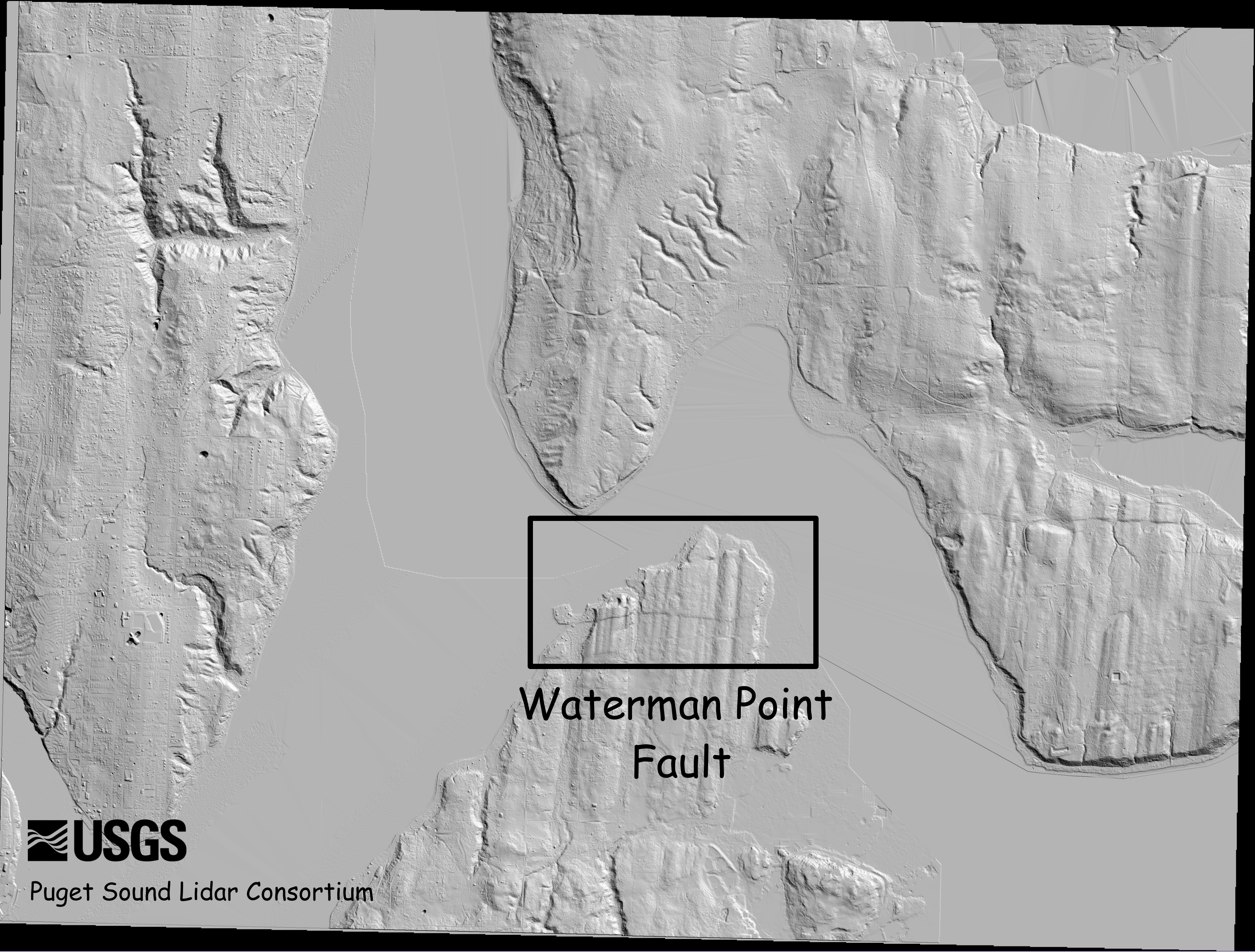
West wall of Crane Lake trench



USGS


Bainbridge Island
Islandwood scarp
Puget Sound
Toe Jam Hill scarp

KOMATSU



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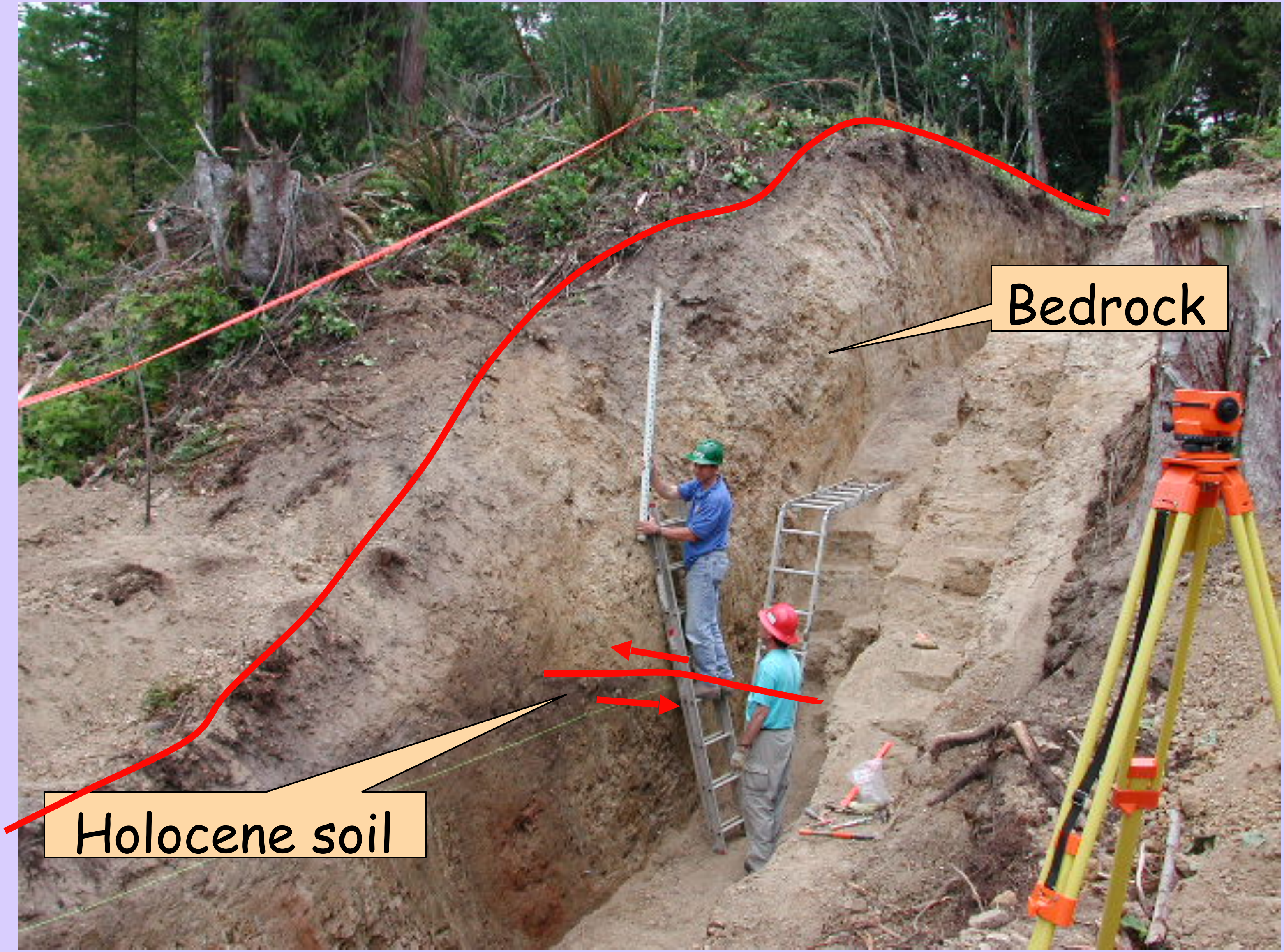
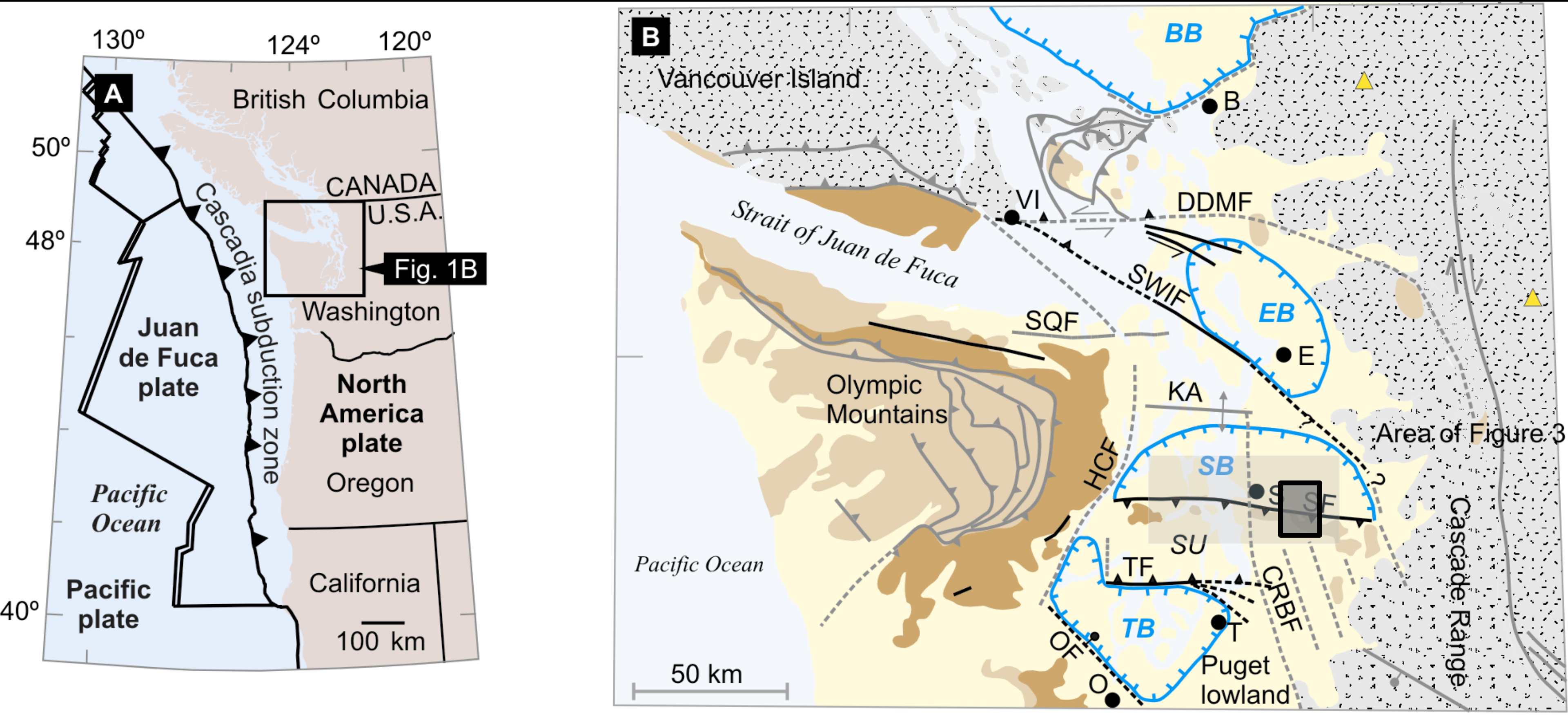

Bedrock
Holocene soil



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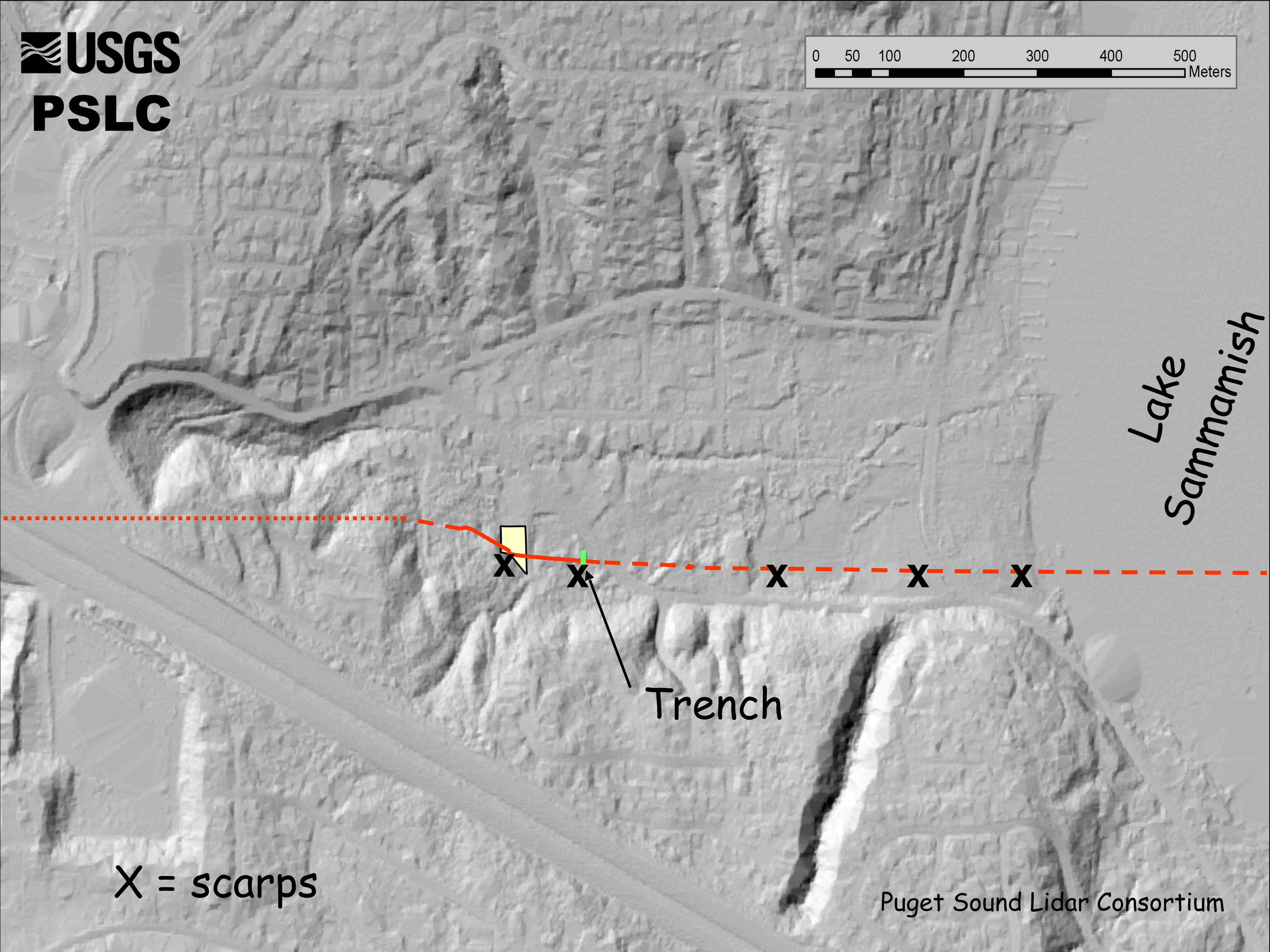
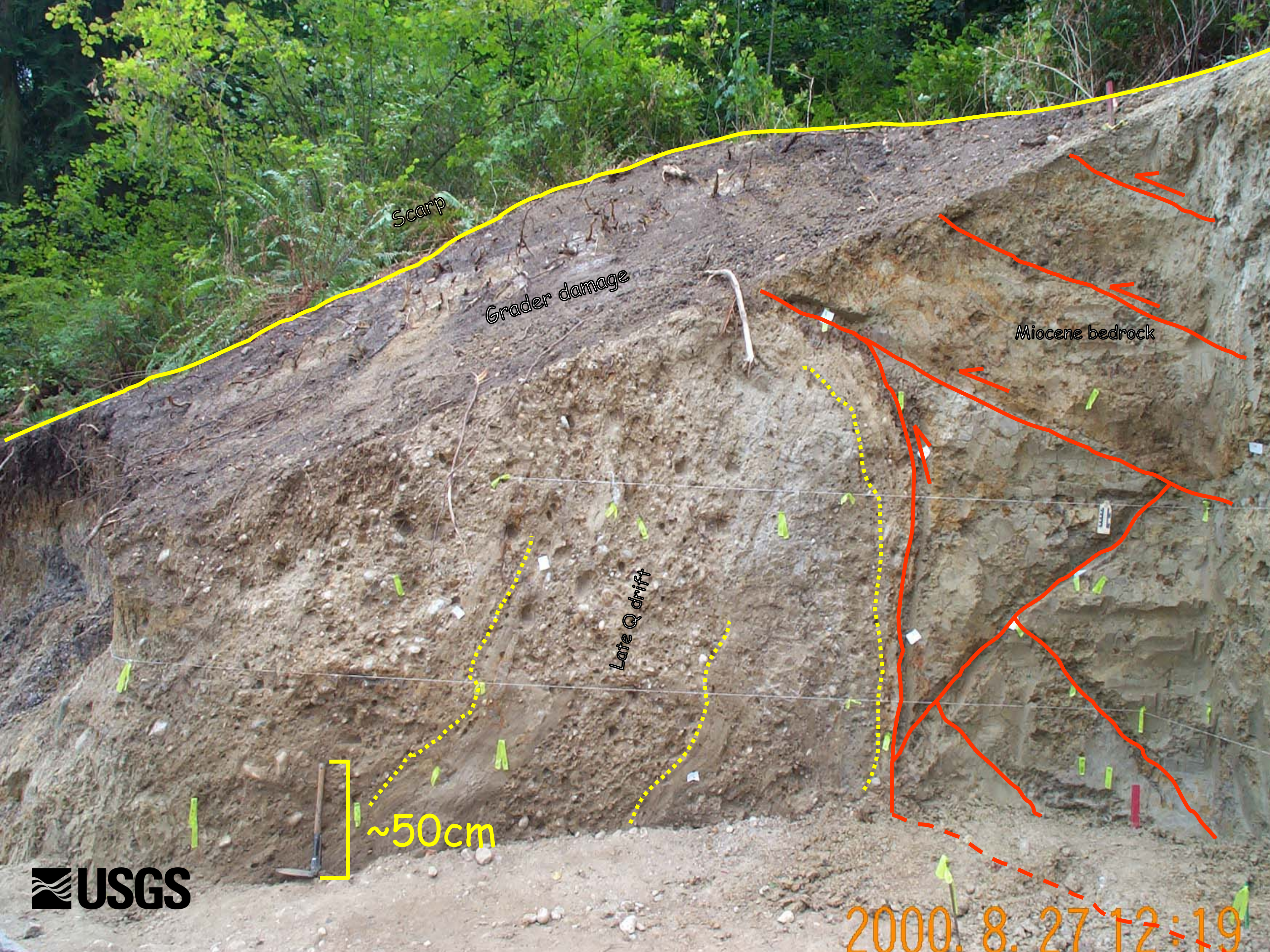
USGS

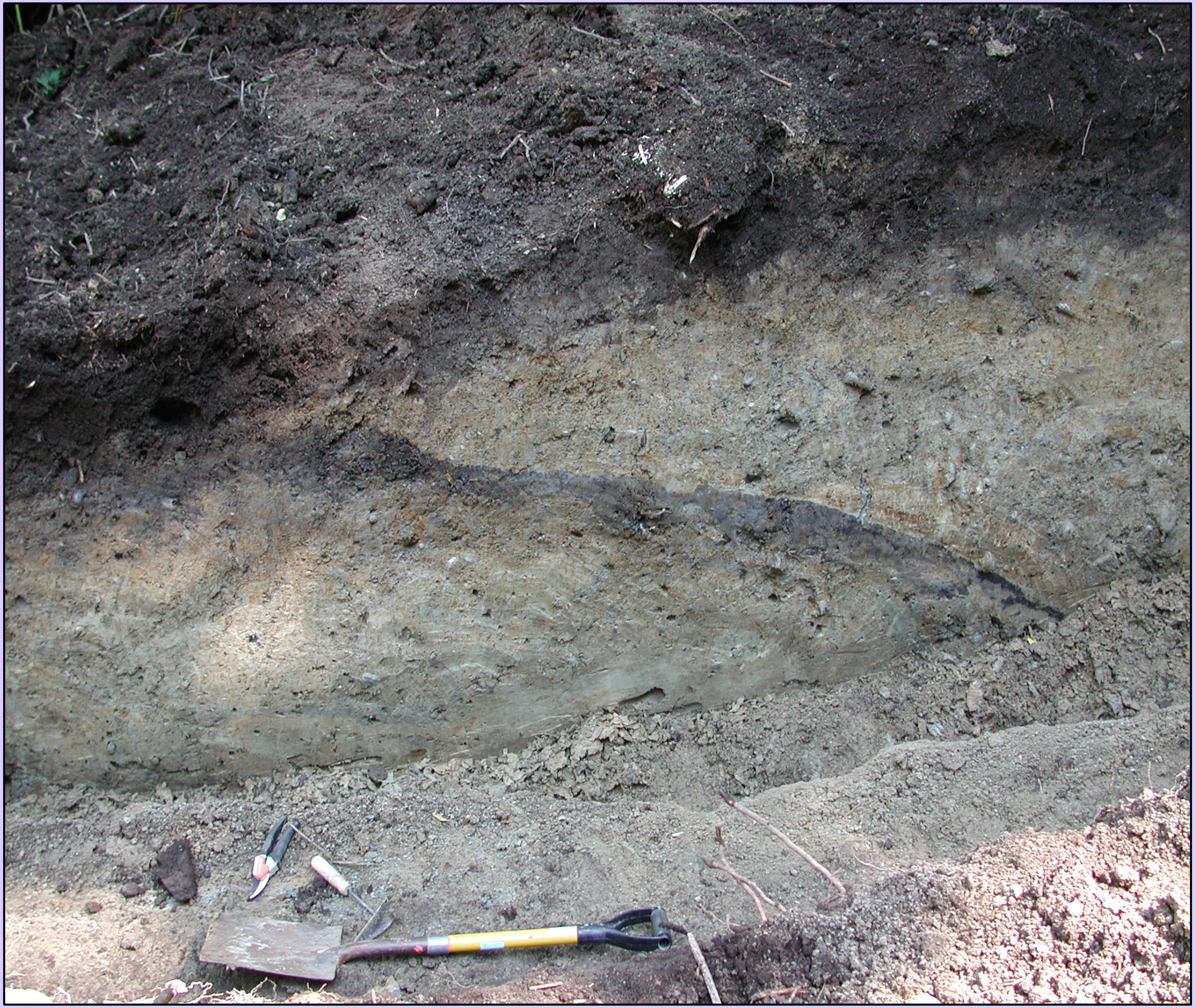
USGS
PSLC

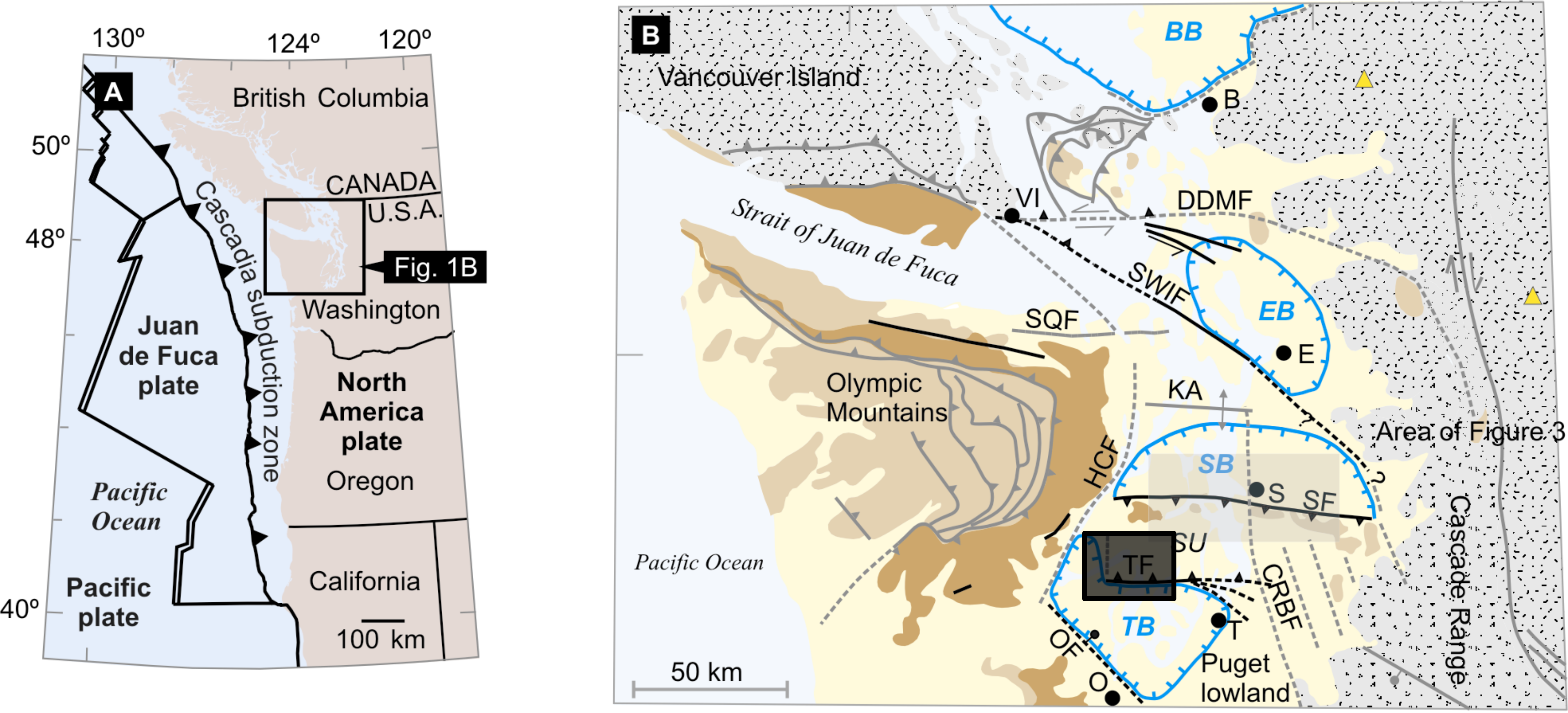


X = scarps

Puget Sound Lidar Consortium


Scarp
Grader damage
Miocene bedrock
Late Q drift
~50cm
USGS
2000. 8. 27 12:19





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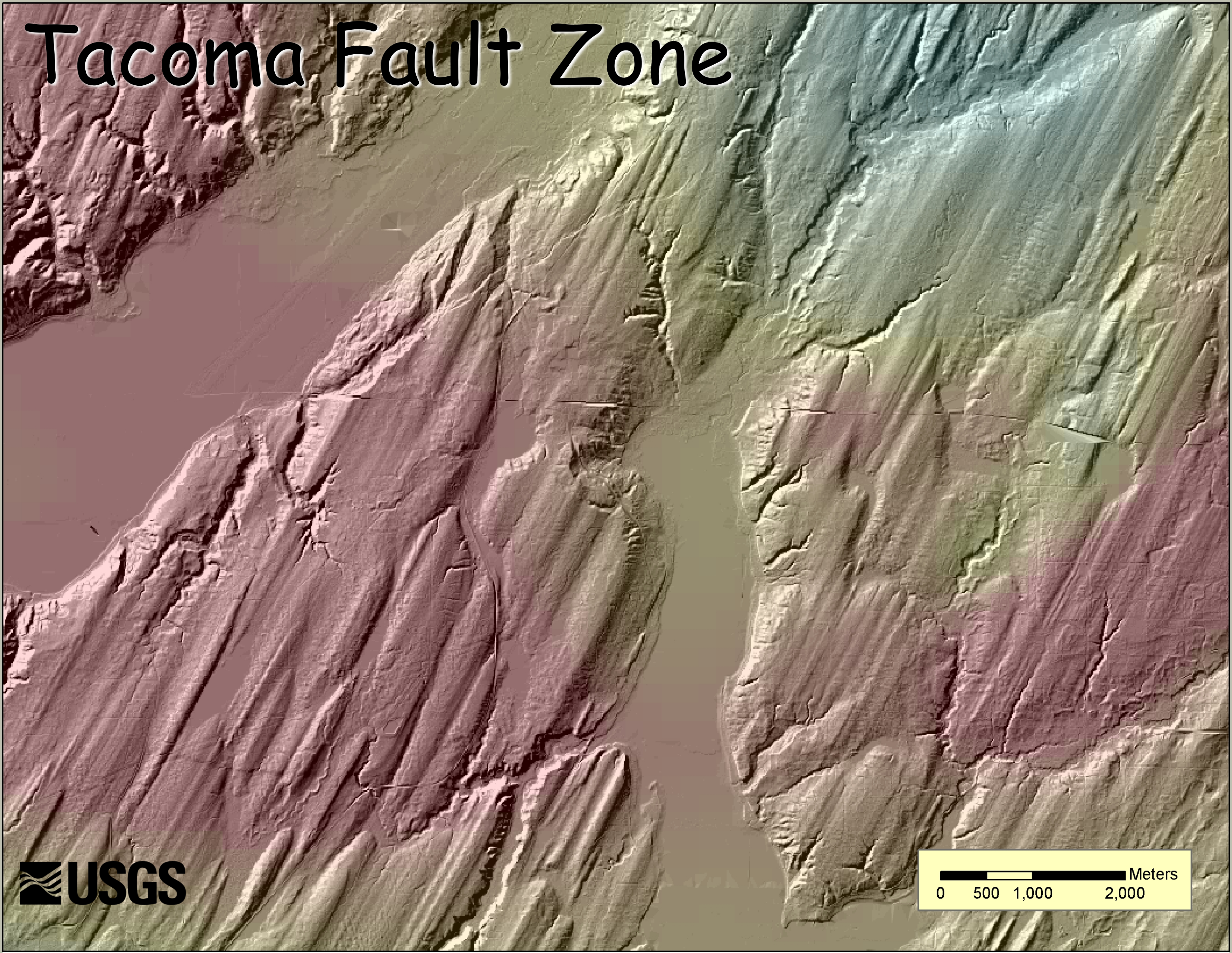
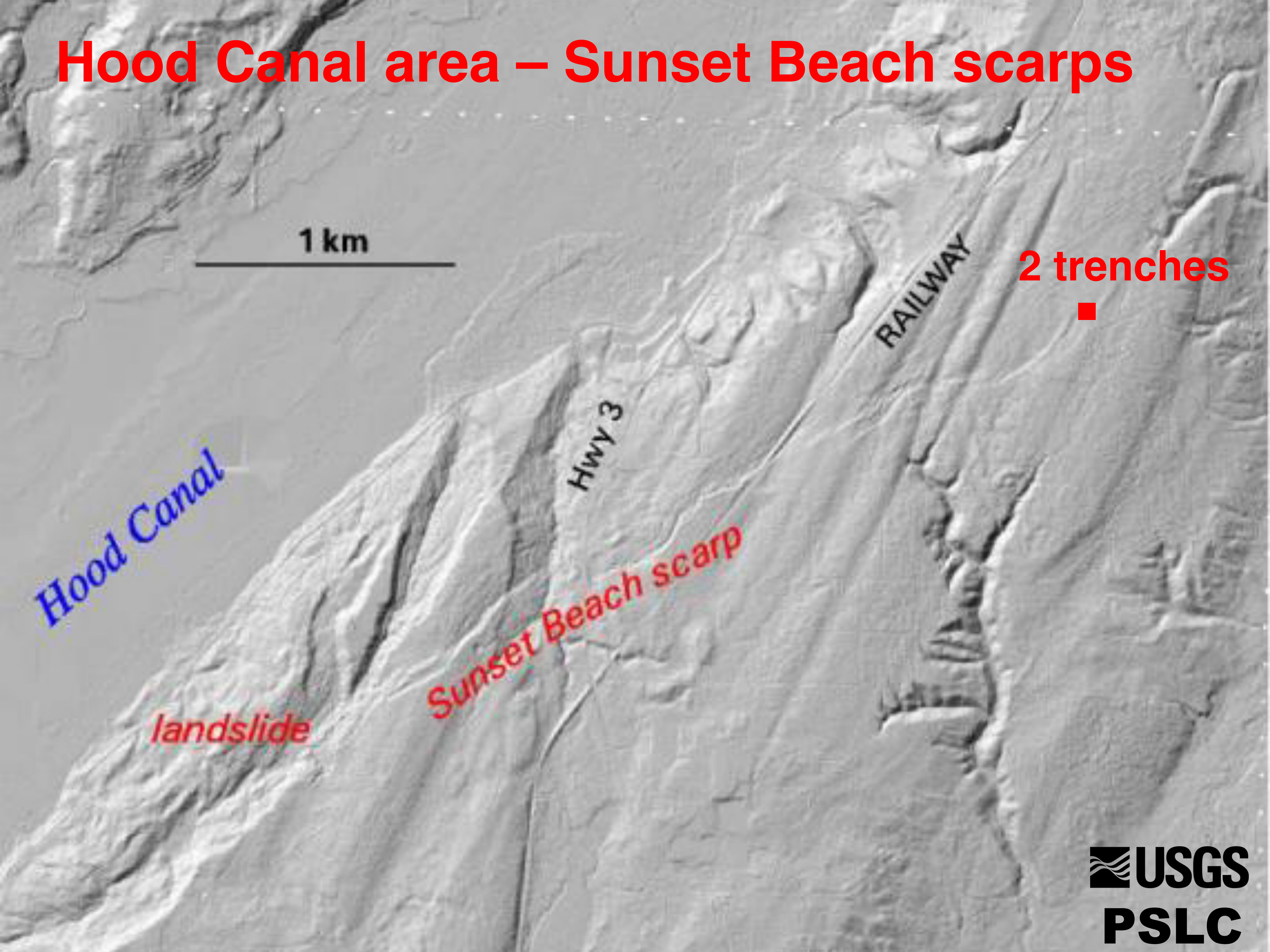
USGS

Tacoma Fault Zone



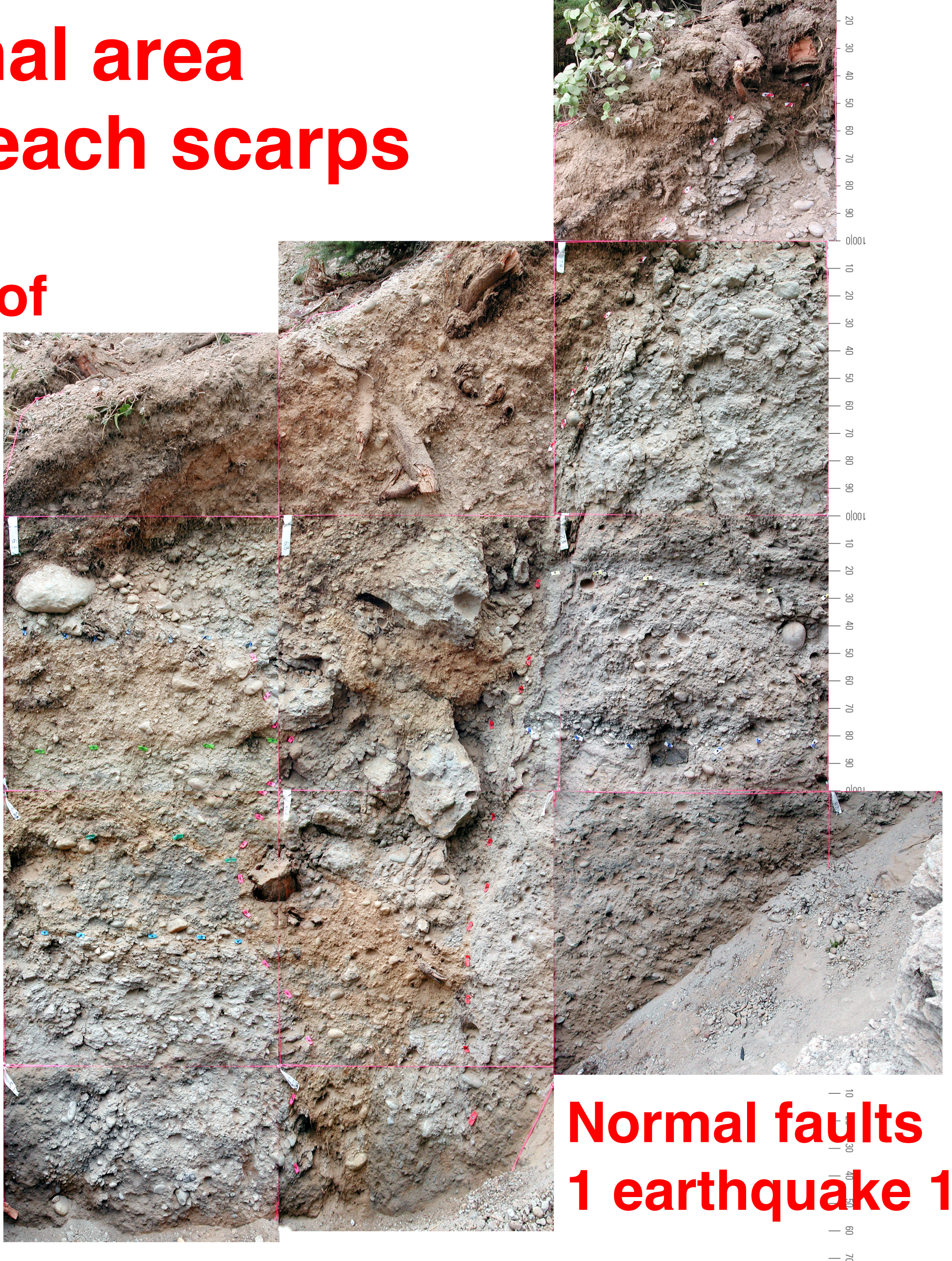
Hood Canal area – Sunset Beach scarps



USGS
PSLC

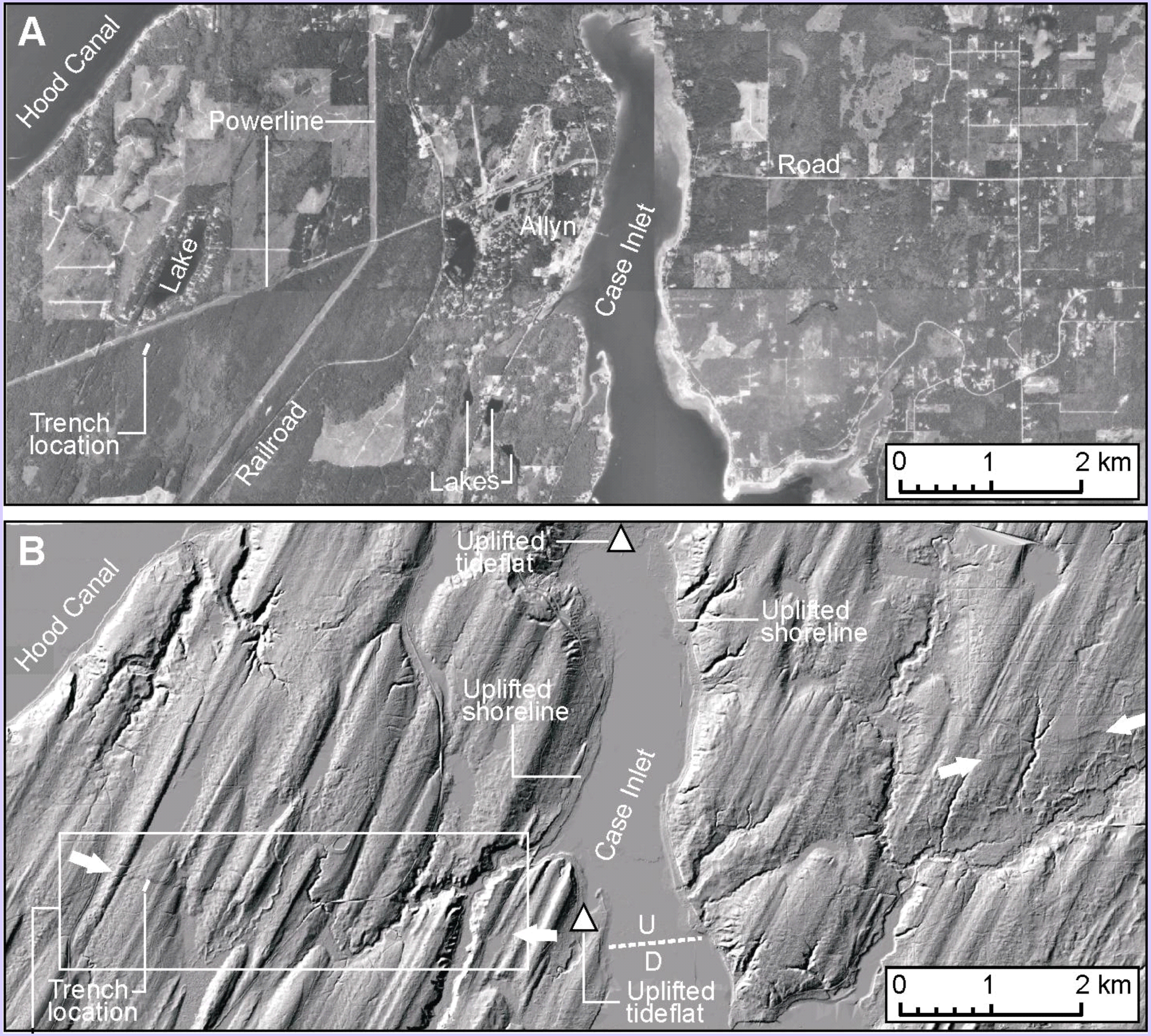
Hood Canal area
Sunset Beach scarps

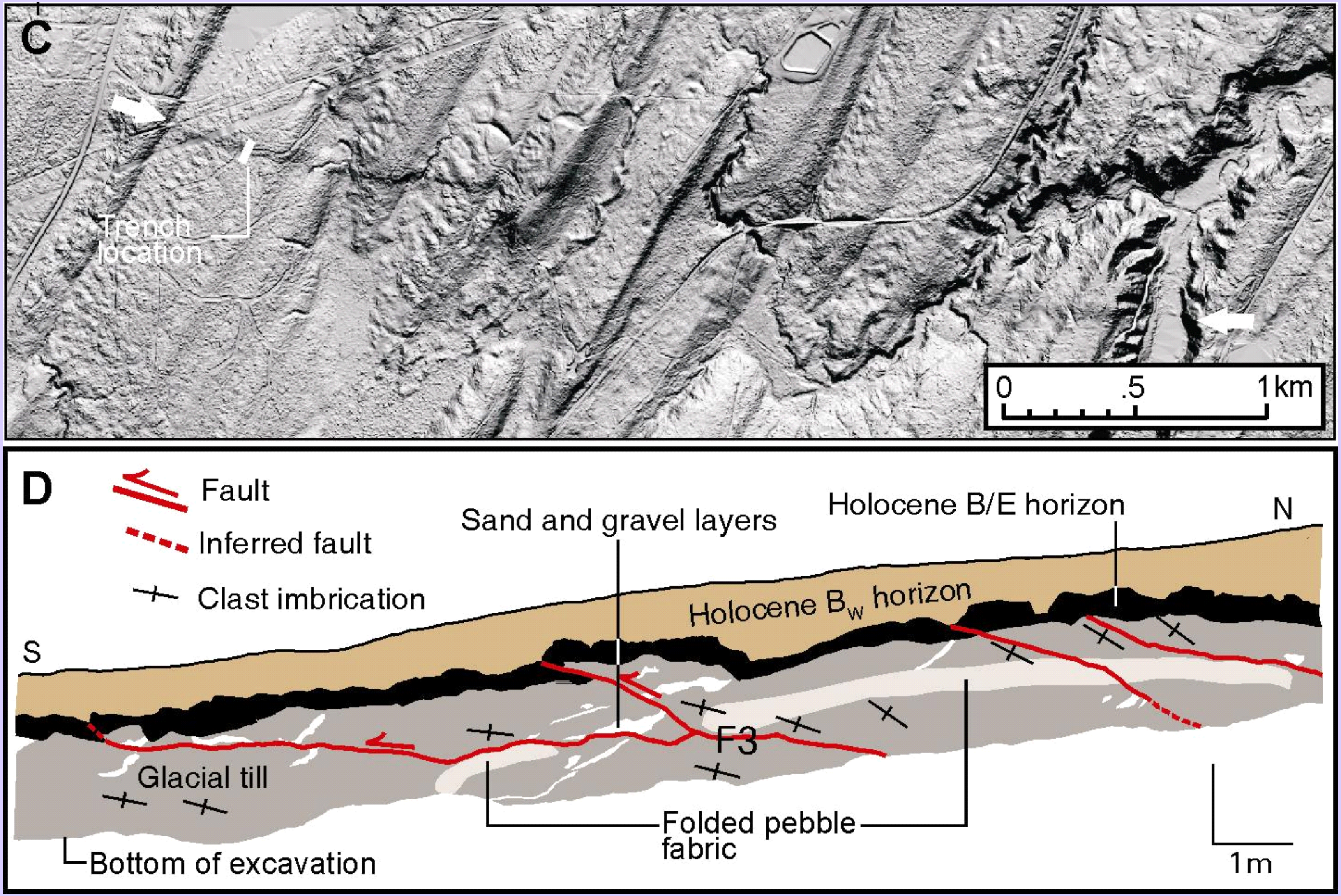
Photomosaic of fault zone in Snake trench



Normal faults

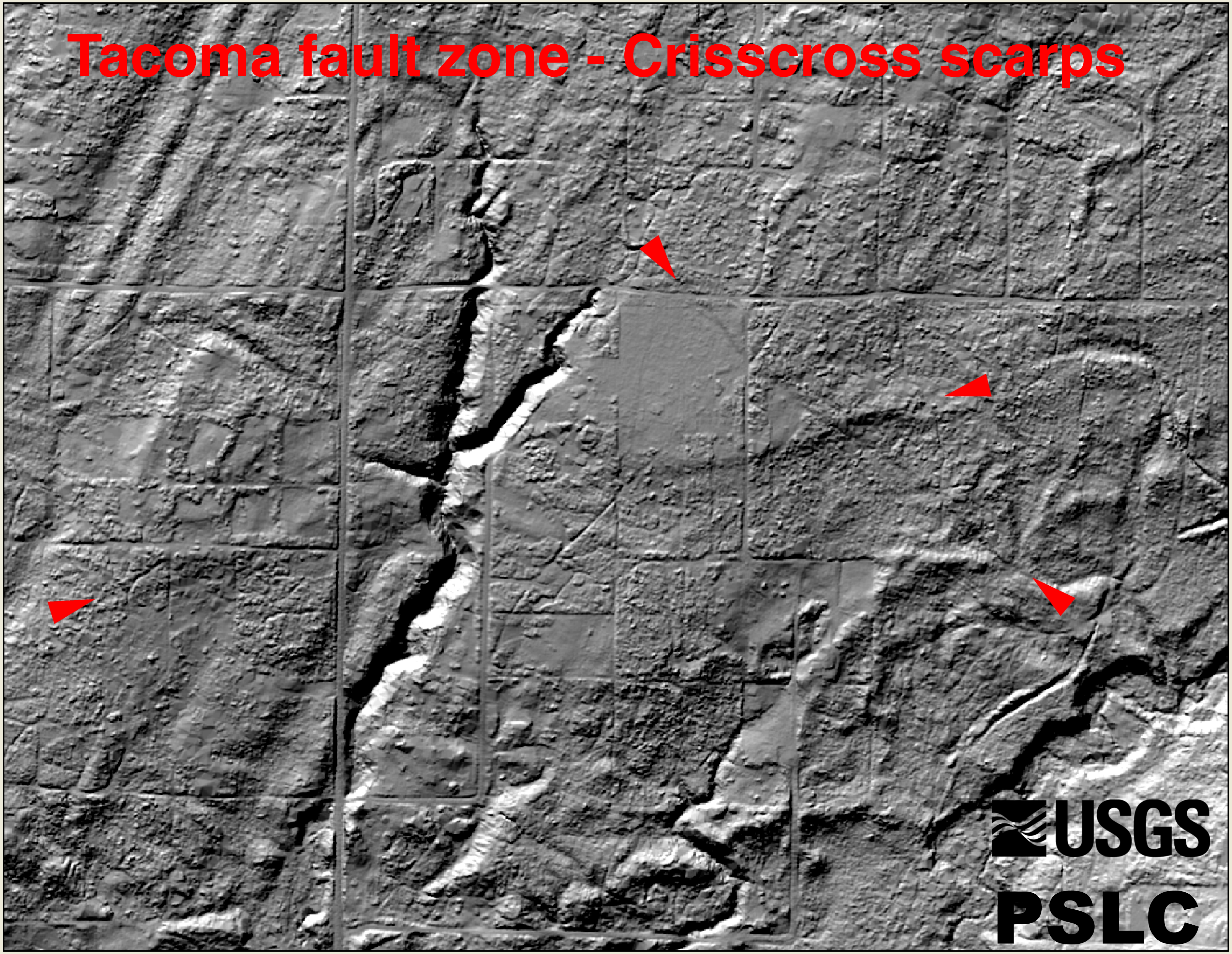
1 earthquake 1.1 ka


A
Hood Canal
Powerline
Road
Allyn
Case Inlet
Lake
Trench location
Railroad
Lakes
0
1
2 km
B
Uplifted tideflat
Hood Canal
Uplifted shoreline
Uplifted shoreline
Case Inlet
U
D
Trench location
Uplifted tideflat
0
1
2 km


C
Trench location
0
.5
1 km
D
Fault
Inferred fault
Clast imbrication
Sand and gravel layers
Holocene B/E horizon
N
S
Holocene B_w horizon
F3
Glacial till
Bottom of excavation
Folded pebble fabric
1 m

USGS

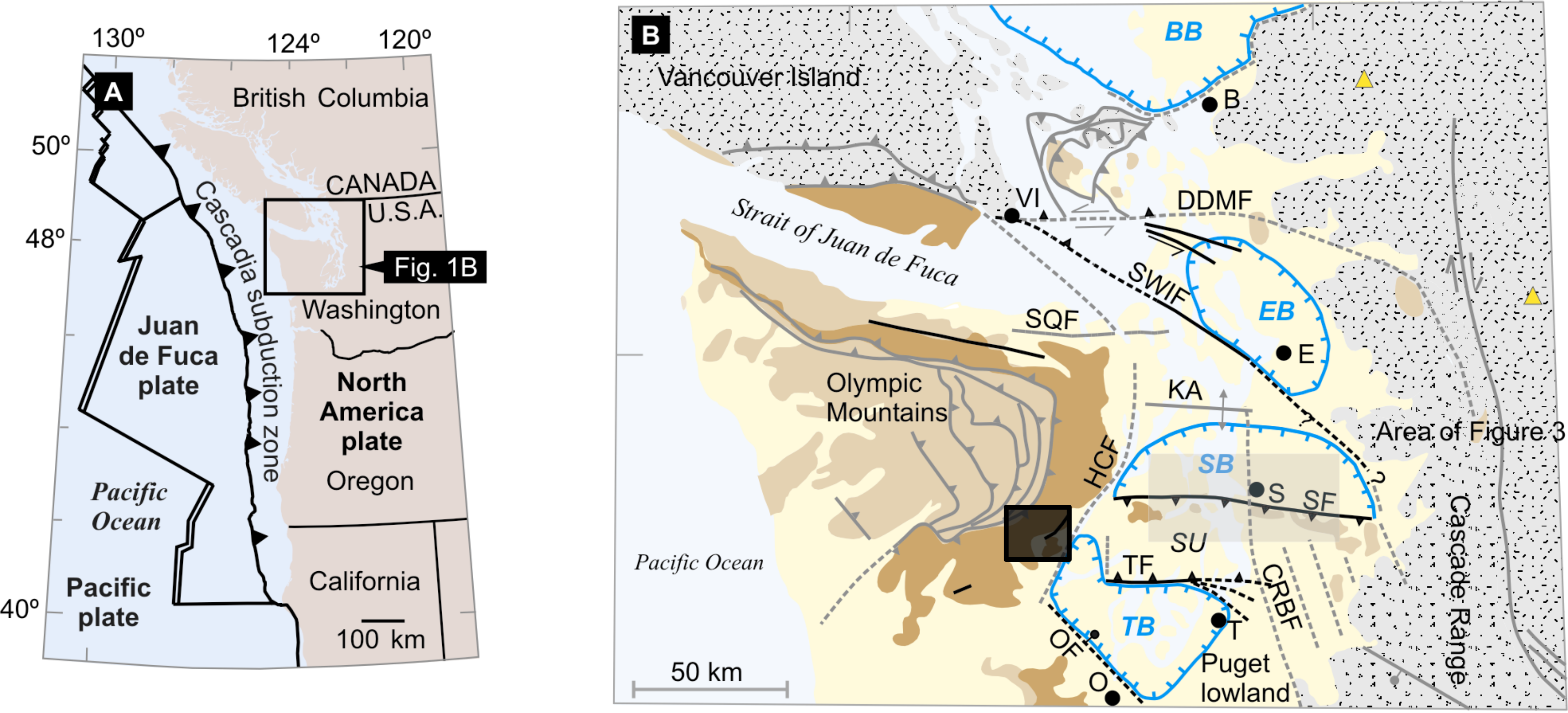
Tacoma fault zone - Crisscross scarps



Tacoma fault zone

Crisscross scarps (larger scarp)

Tacoma fault zone
Crisscross scarps (smaller scarp)



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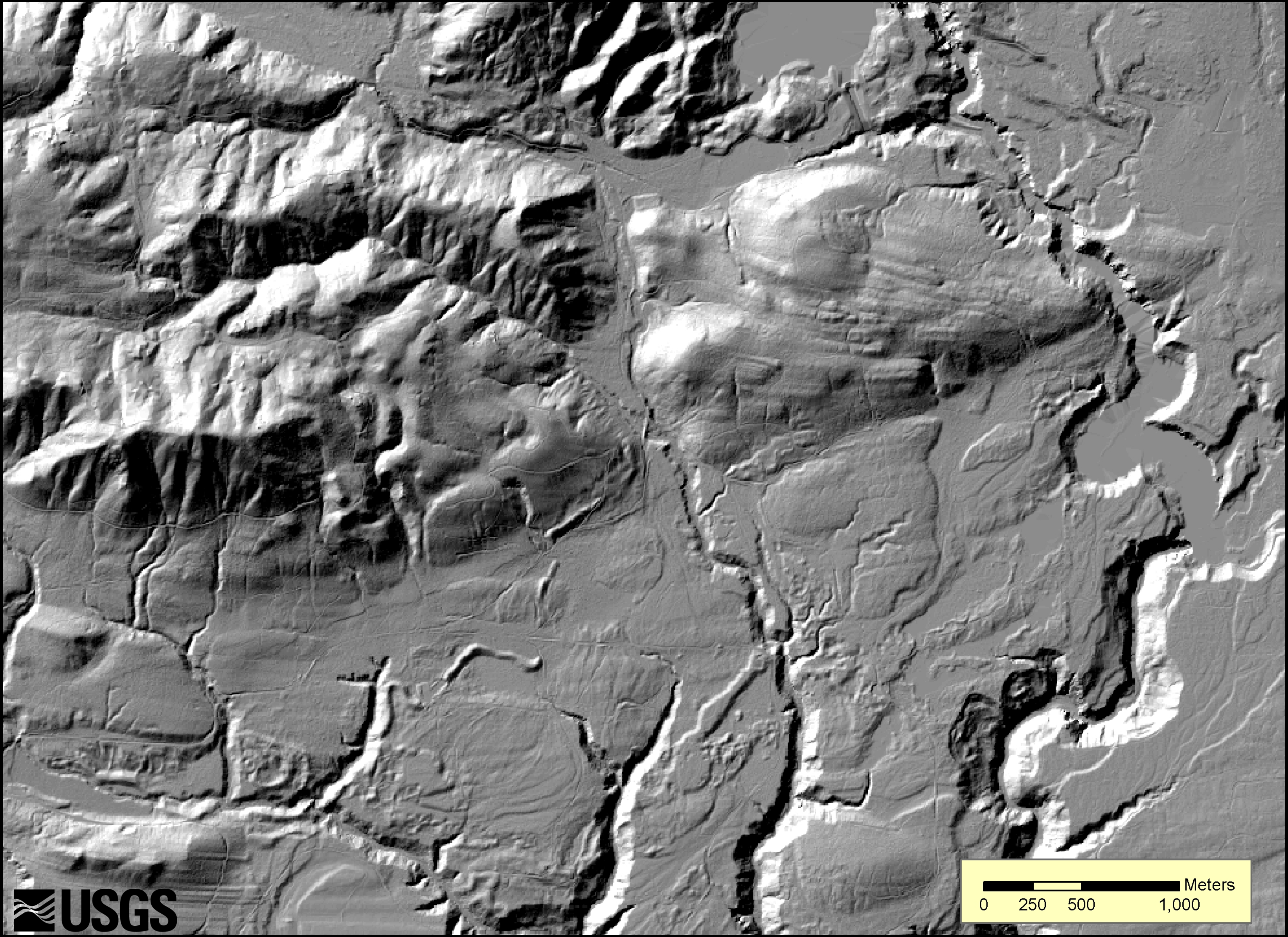
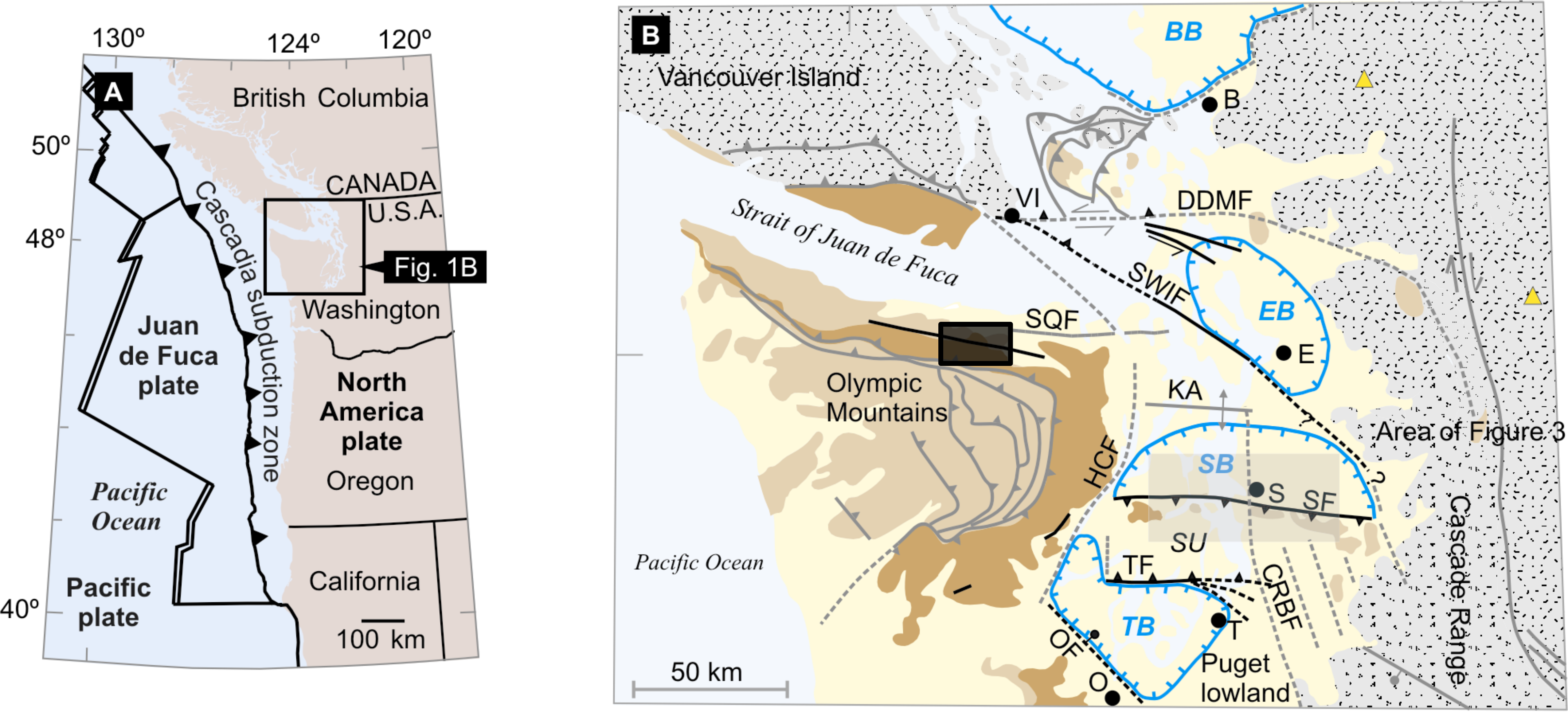

Meters
0
250
500
1,000



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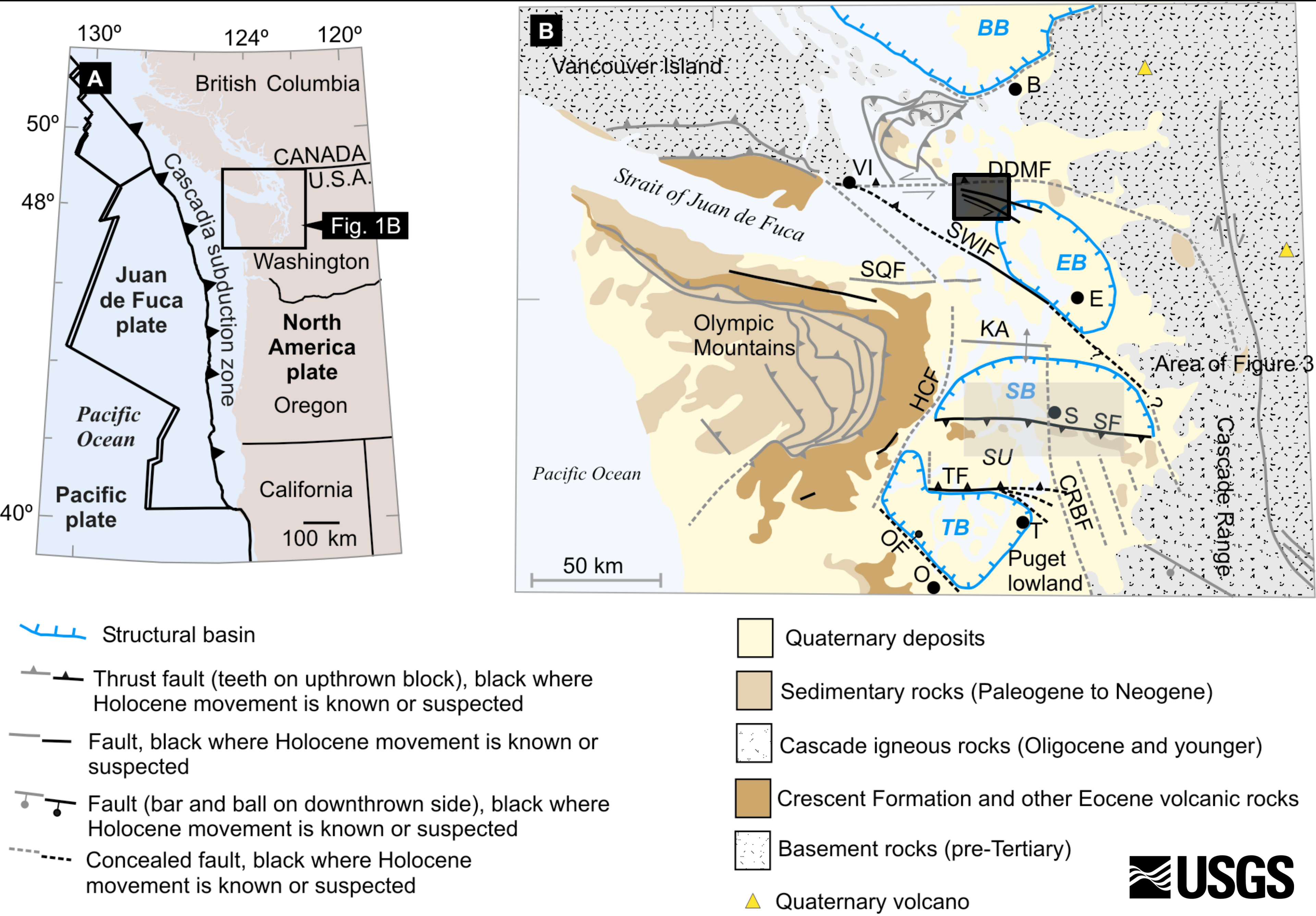
North flank Olympic Mts.
Little River fault
Mt. Pleasant graben scarps

Normal fault,
2 earthquakes <2.0 ka


A
130º
124º
120º
50º
48º
40º
British Columbia
CANADA
U.S.A.
Fig. 1B
Washington
Cascadia subduction zone
Juan de Fuca plate
North America plate
Oregon
Pacific Ocean
Pacific plate
California
100 km
B
Vancouver Island
BB
B
VI
DDMF
Strait of Juan de Fuca
SWIF
EB
E
SQF
KA
Olympic Mountains
Area of Figure 3
SB
S
SF
HCF
SU
TF
CRBF
TB
T
OF
O
Puget lowland
Cascade Range
Pacific Ocean
50 km
Structural basin
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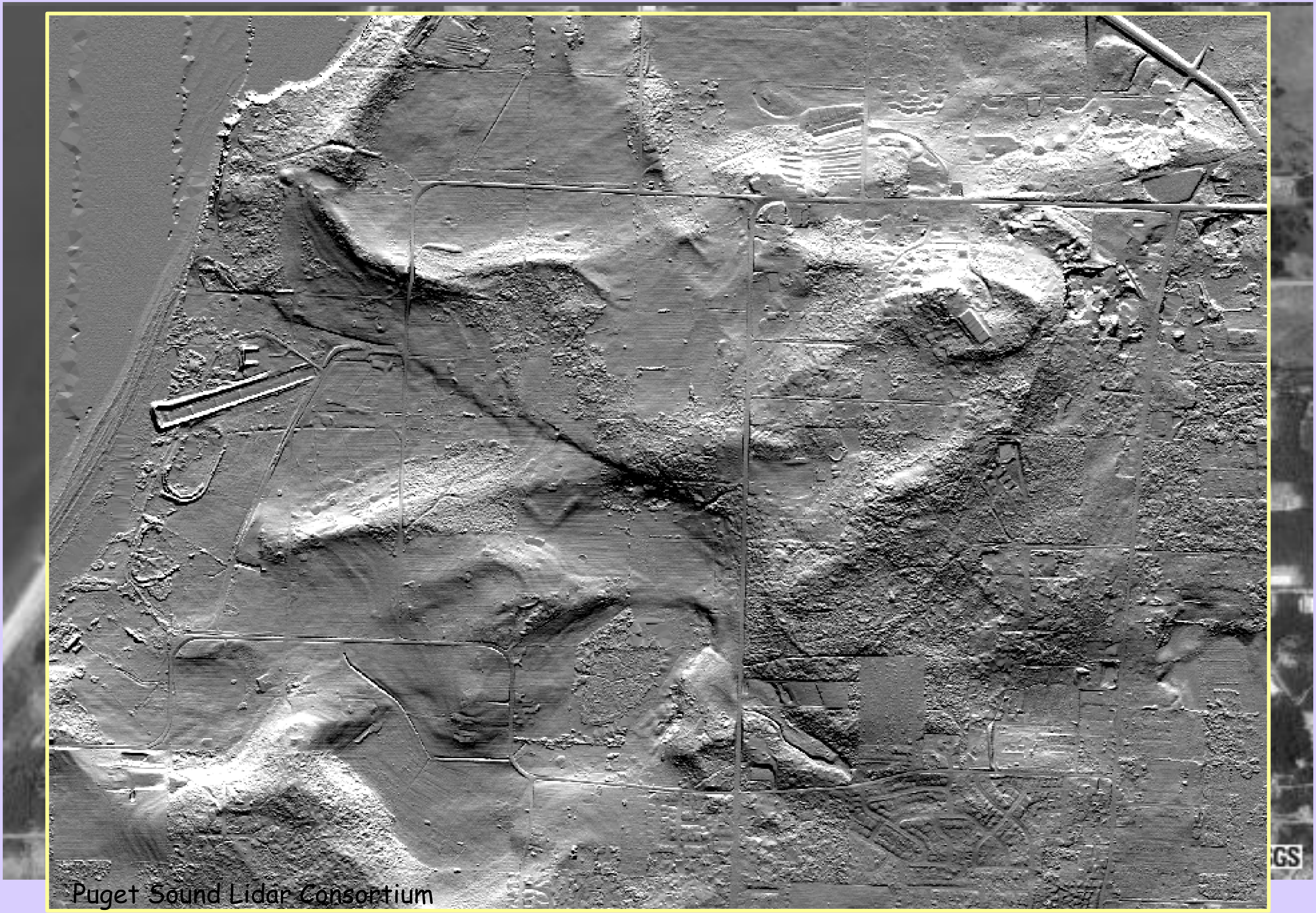
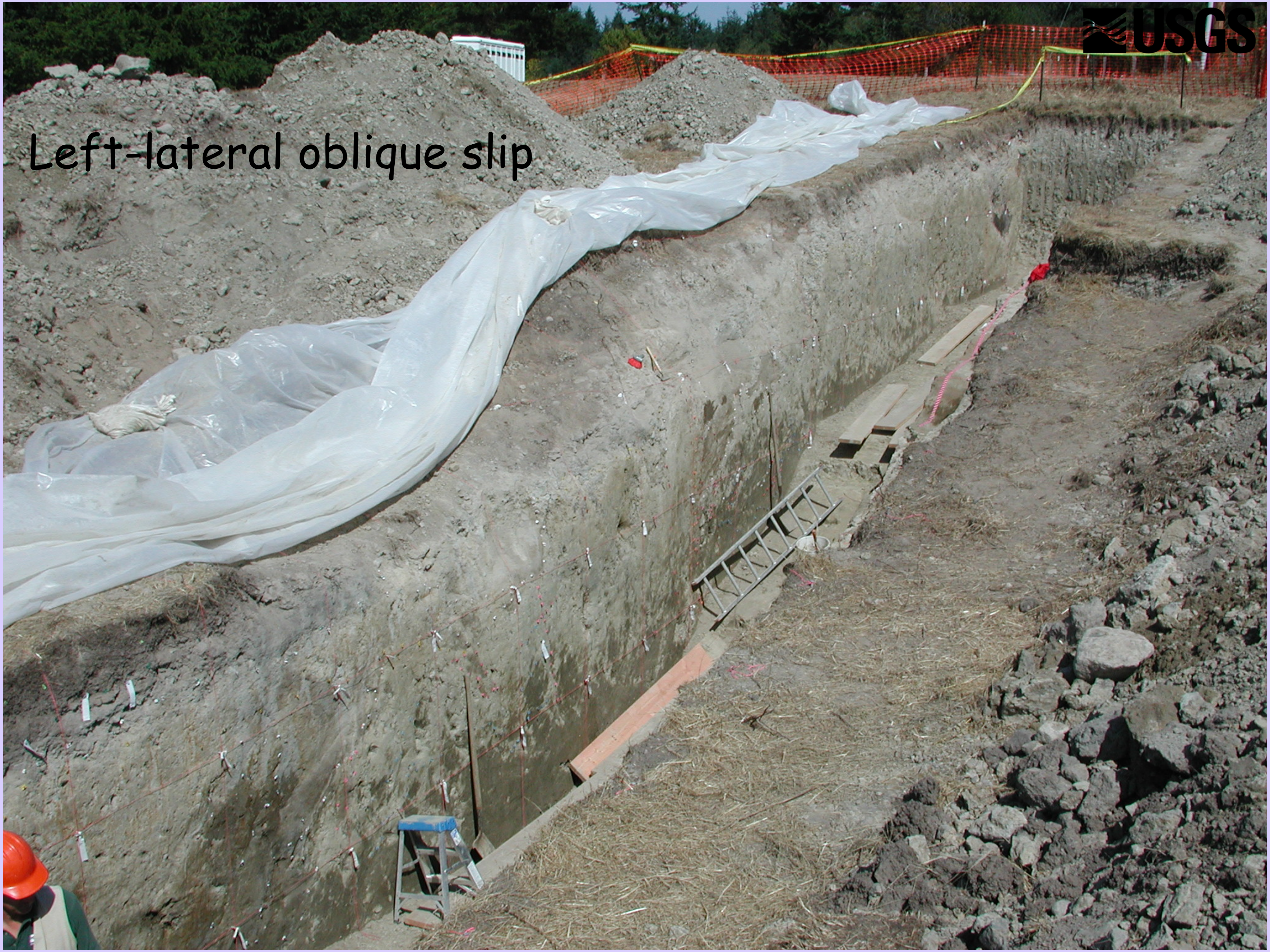
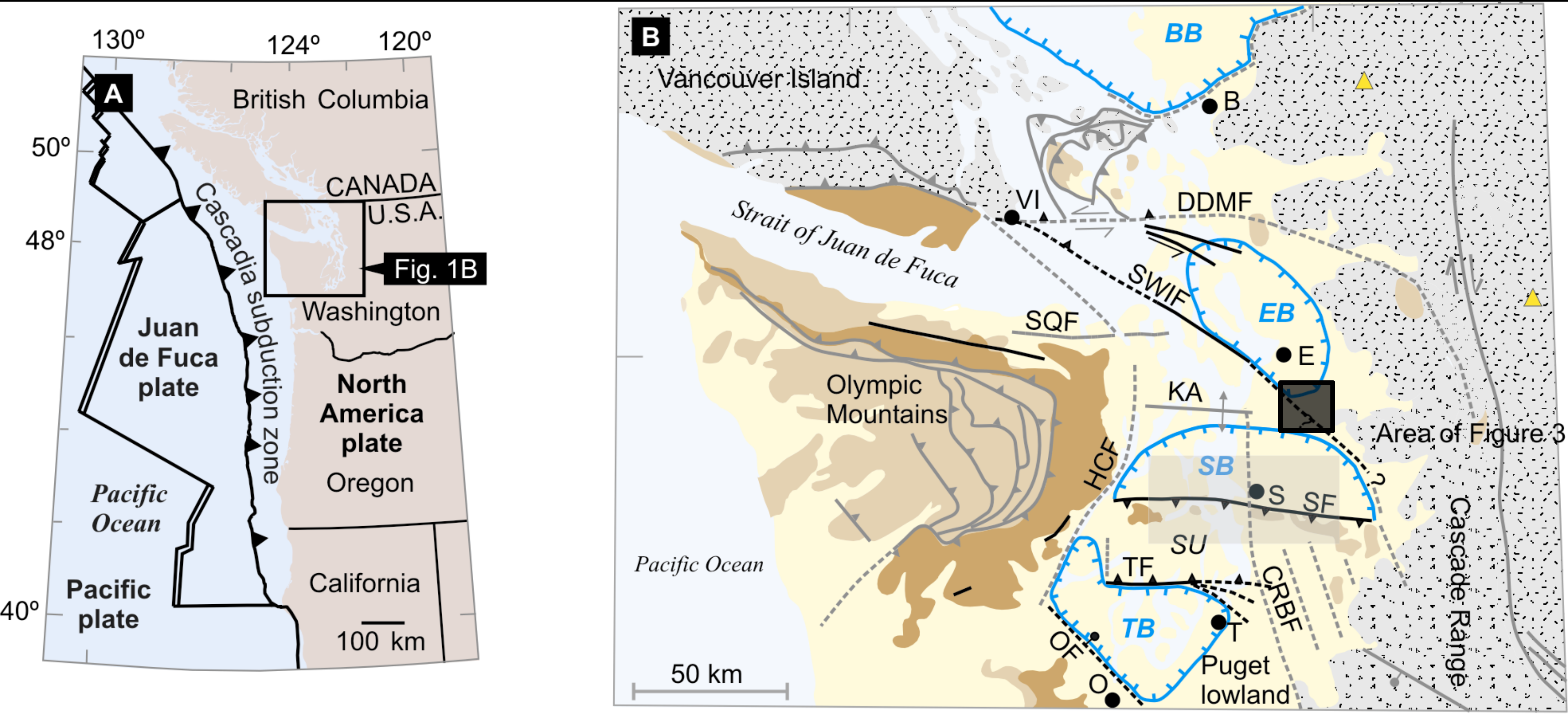
Quaternary volcano



Puget Sound Lidar Consortium


Left-lateral oblique slip

Possibly two events: ~1200-1000 yr BP and ~100-500 yr BP



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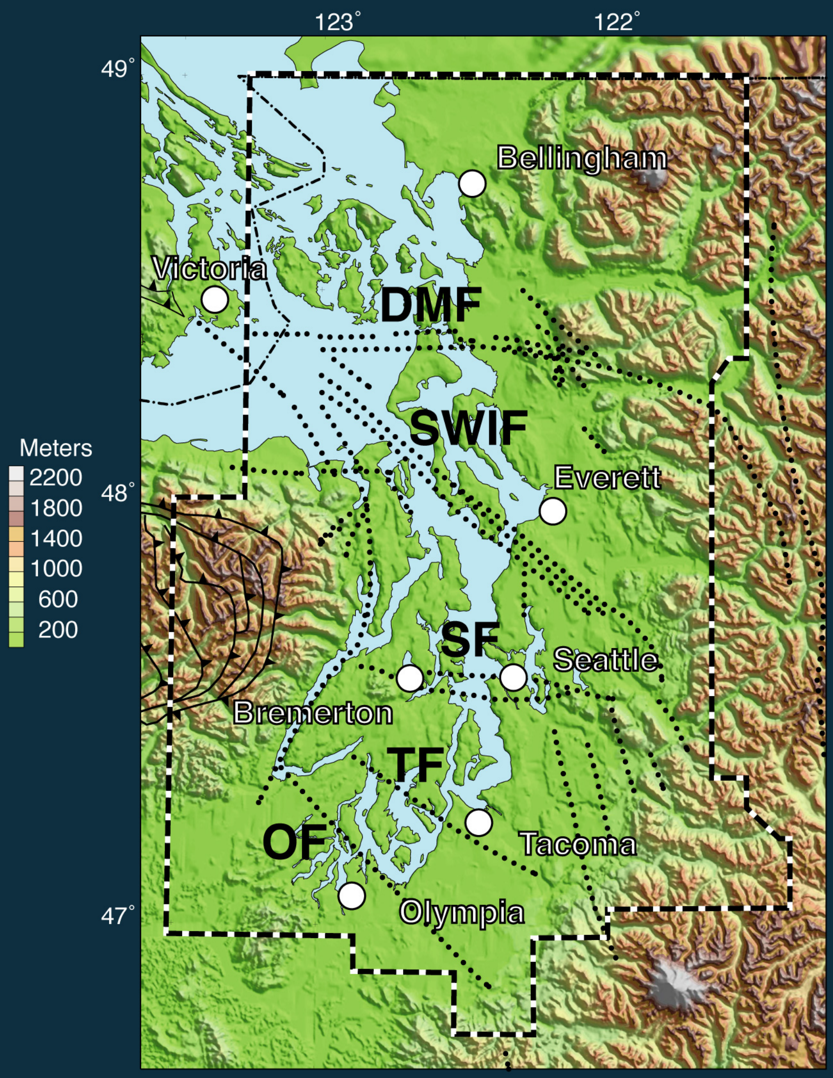
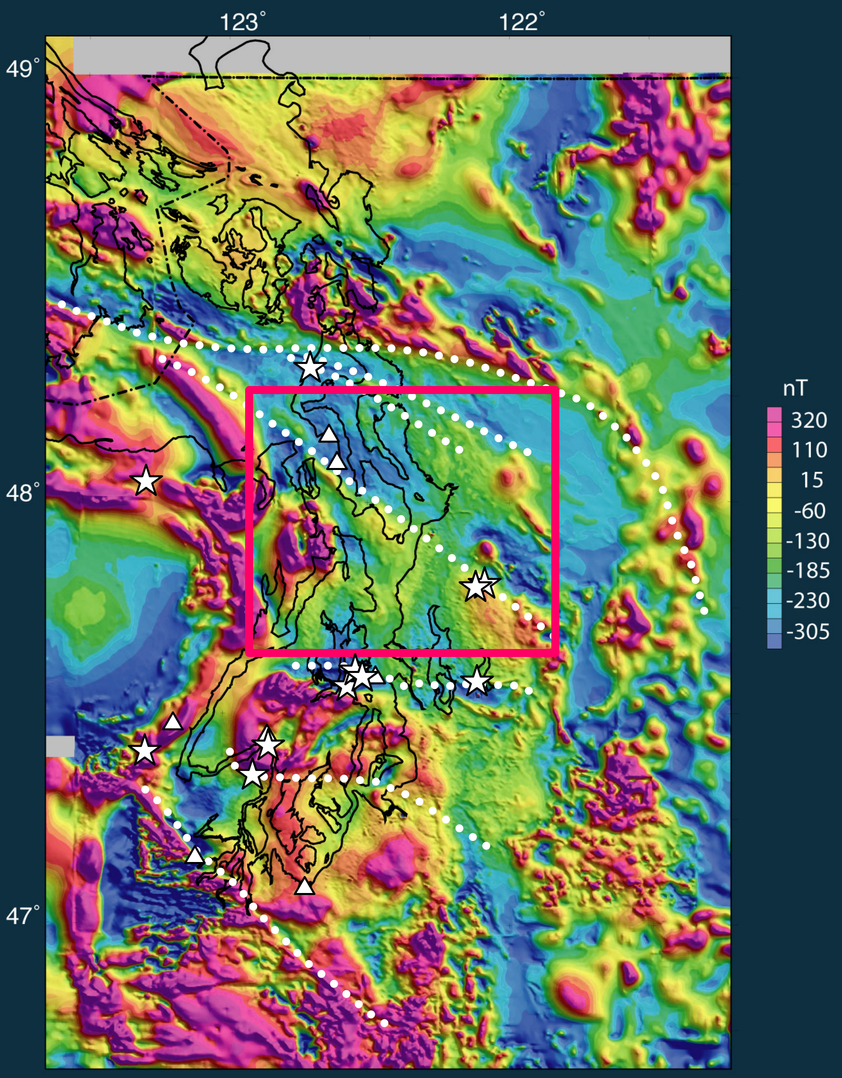
- ▲ Quaternary volcano

Terrain



Magnetic Intensity



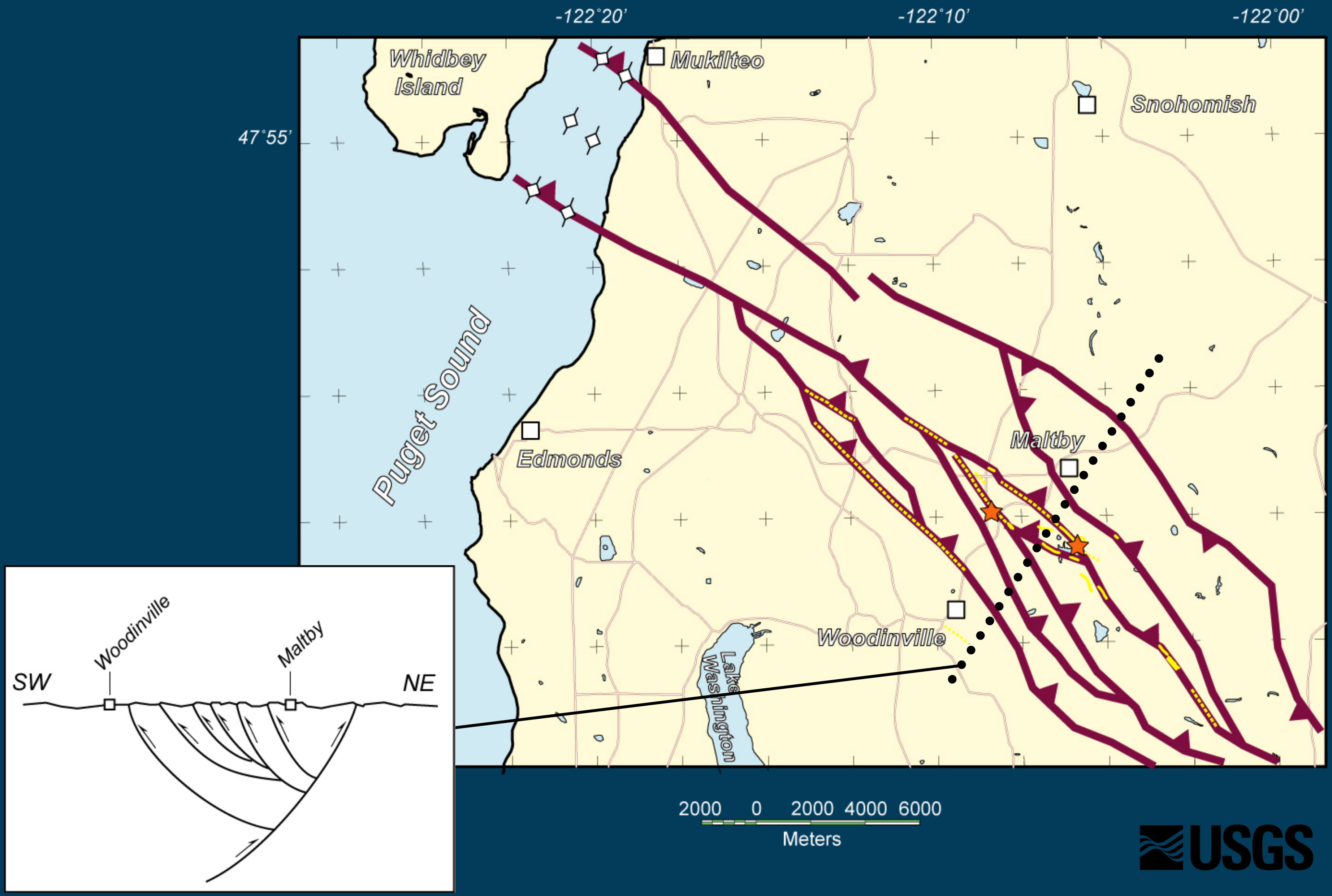
0 20 40 60 KM

Holocene deformation

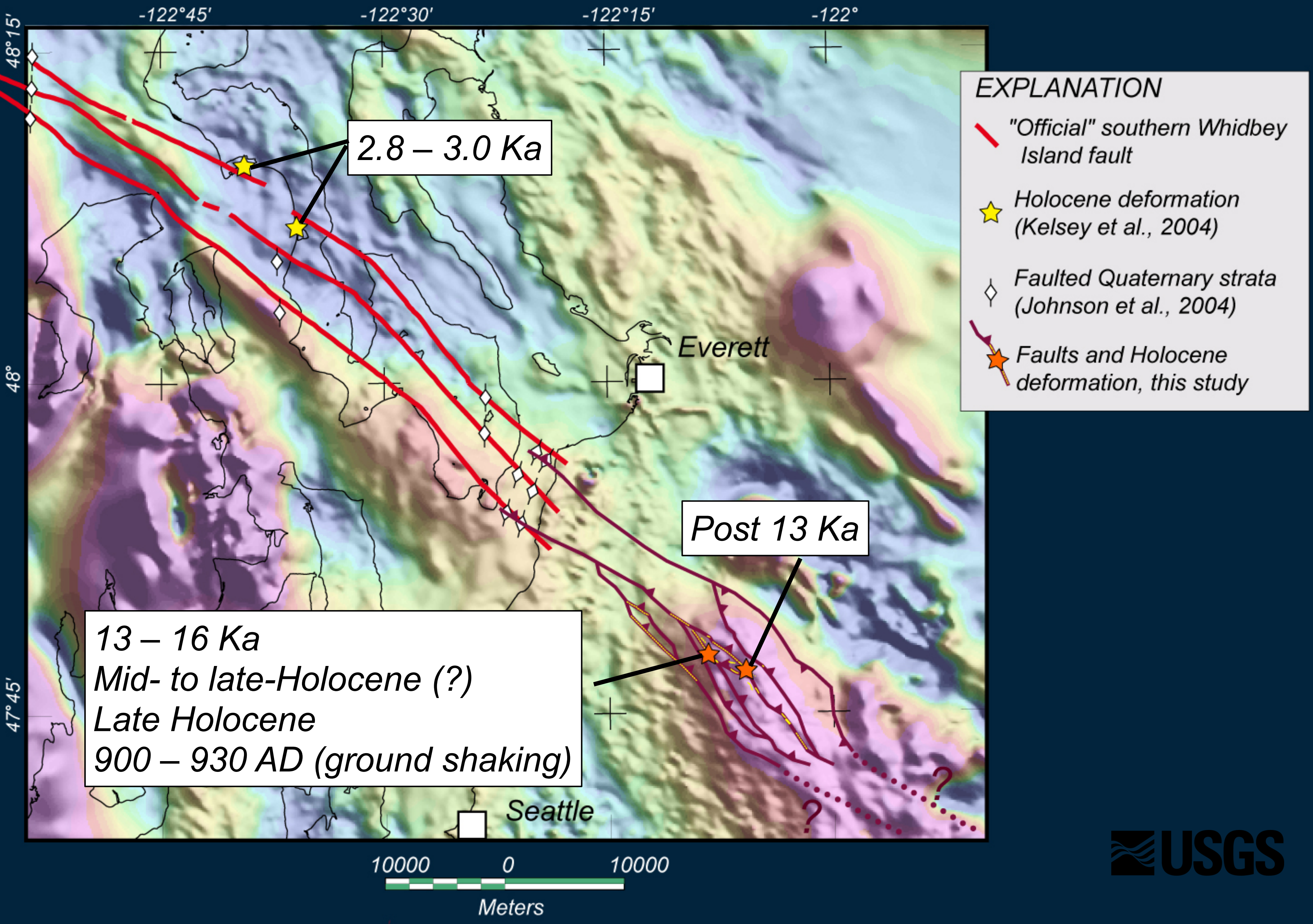
★ *Trench excavation*

△ *Other evidence*

Onshore Extension, Southern Whidbey Island Fault



Aeromagnetic Anomalies and the Southern Whidbey Island Fault



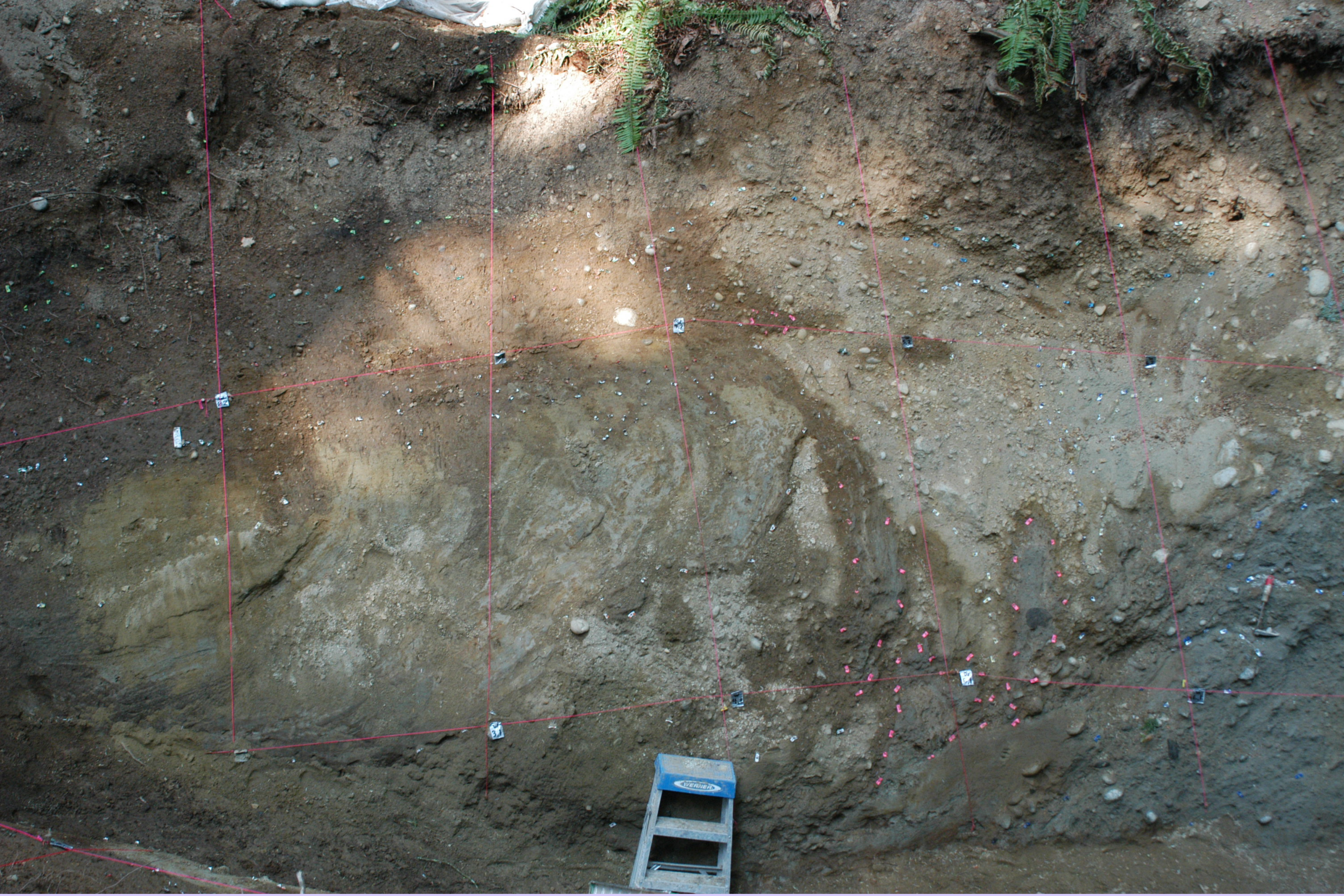
2.8 – 3.0 Ka

Post 13 Ka

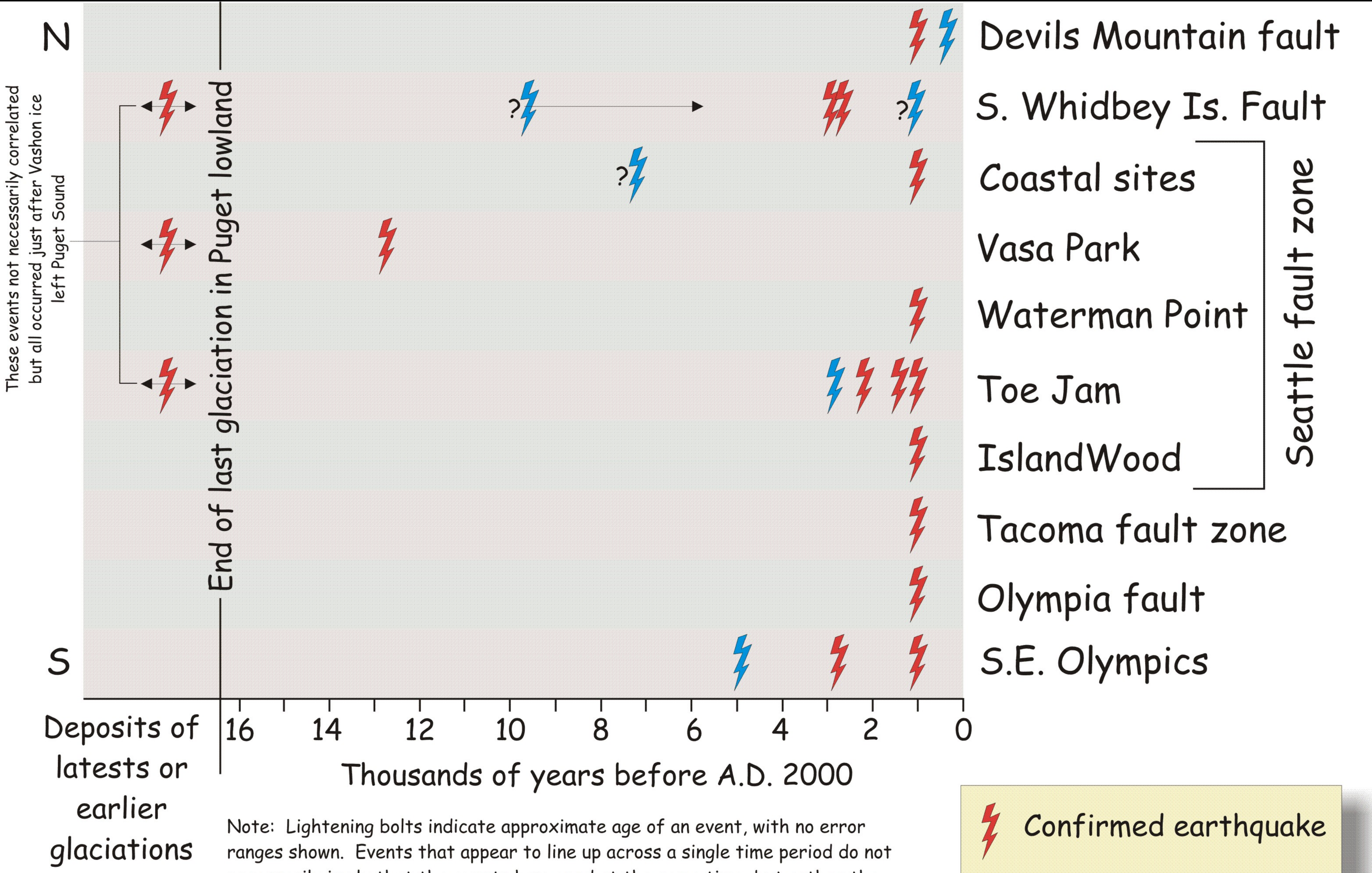
13 – 16 Ka
Mid- to late-Holocene (?)
Late Holocene
900 – 930 AD (ground shaking)

EXPLANATION

- *"Official" southern Whidbey Island fault*
- ☆ *Holocene deformation (Kelsey et al., 2004)*
- ◇ *Faulted Quaternary strata (Johnson et al., 2004)*
- *Faults and Holocene deformation, this study*



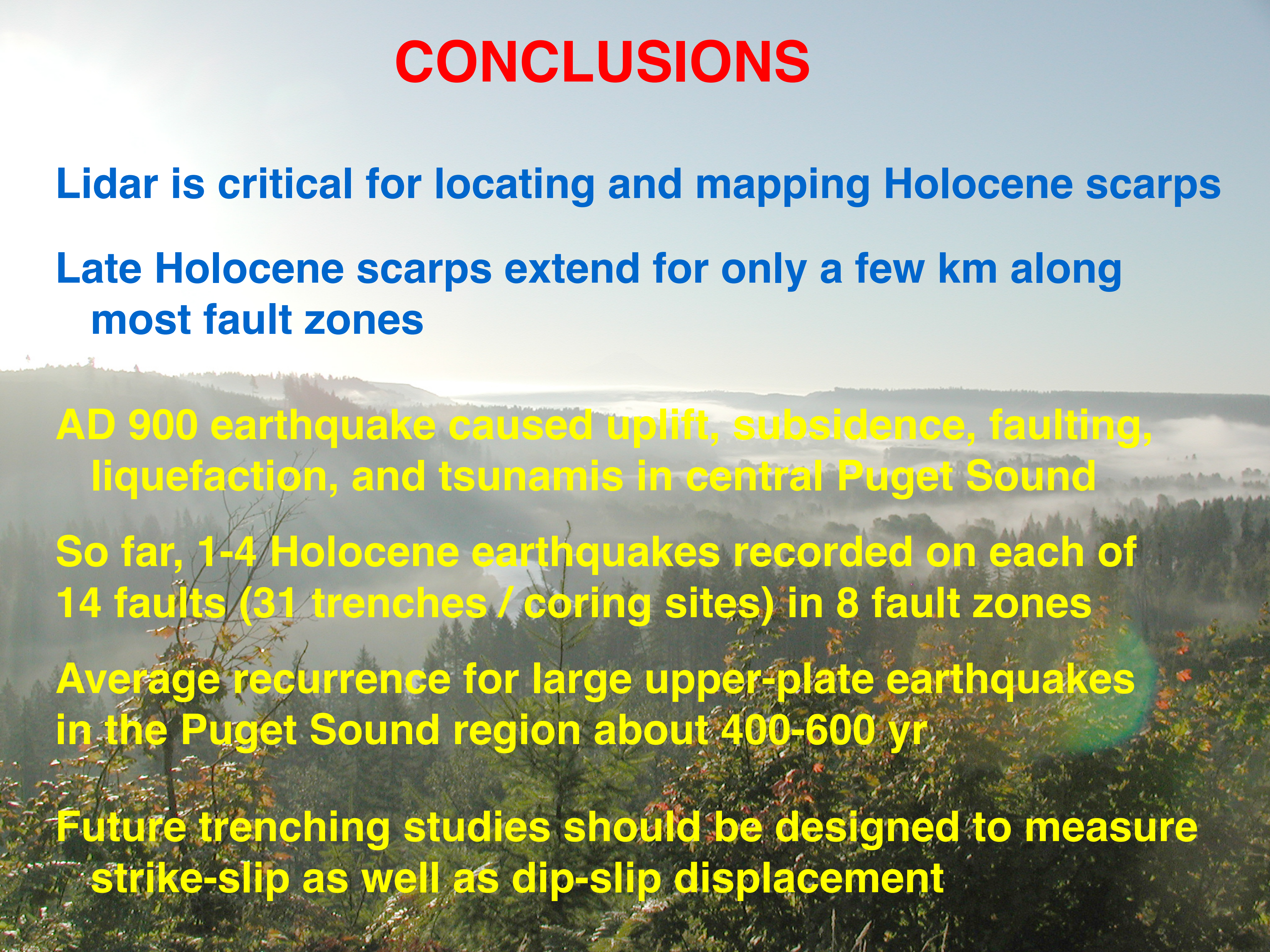
Crystal Lake and Brightwater trenches – 1 to possibly 4 events in last 16,000 years



Note: Lightening bolts indicate approximate age of an event, with no error ranges shown. Events that appear to line up across a single time period do not necessarily imply that the events happened at the same time, but rather the events could have occurred as a single large event that ruptured several faults at the same time or as a series of events on multiple faults separated by years to decades (the radiocarbon dates typically do not allow correlation below several decades).

Confirmed earthquake

Possible earthquake



CONCLUSIONS

Lidar is critical for locating and mapping Holocene scarps

Late Holocene scarps extend for only a few km along most fault zones

AD 900 earthquake caused uplift, subsidence, faulting, liquefaction, and tsunamis in central Puget Sound

So far, 1-4 Holocene earthquakes recorded on each of 14 faults (31 trenches / coring sites) in 8 fault zones

Average recurrence for large upper-plate earthquakes in the Puget Sound region about 400-600 yr

Future trenching studies should be designed to measure strike-slip as well as dip-slip displacement